State of Illinois
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
Division of Highways
Bureau of Research and Development

PAVED SHOULDER PROBLEM - STEVENSON EXPRESSWAY

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Condition Survey of Route U.S. 66

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The field work covered by this report was conducted principally by field forces of District 10 of the Illinois Division of Highways under the immediate supervision of J. H. Lacis and was reported initially by Mr. Lacis.

The opinions, findings, and conclusions expressed in this report are those of the Illinois Division of Highways and not necessarily those of the Bureau of Public Roads.

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SUMMARY

Soon after the opening in the fall of 1964 of the Stevenson Expressway (I-55) entering Chicago from the southwest, an extreme upward displacement of the bituminous-paved shoulder with respect to the adjacent portland cement concrete pavement was noted. The vertical displacement was accompanied by some lateral displacement, the frequent occurrence of longitudinal cracks about a foot from the pavement edge, and a considerable amount of random cracking between the longitudinal crack and the interface of the pavement and shoulder.

Three kinds of material were used in the shoulder base courses: (1) cement-aggregate mixture (CAM); (2) pozzolan-aggregate mixture (PAM); and (3) bituminous-aggregate mixture (BAM). Except for a slight vertical displacement, the deficiencies were confined to locations where the CAM and PAM shoulder bases had been used.

Field and laboratory investigations have led to the following conclusions and recommendations.

Conclusions

The displacement and attendant distress suffered by the paved shoulders of the Stevenson Expressway appear to have originated through the exposure of frost-susceptible and expansive material to excessive amounts of surface water. Several factors seem to have acted either in combination or separately to aggravate the condition, among them being:

(1) an embankment soil especially susceptible to frost expansion when exposed to large quantities of water; also one capable of expansion when exposed to moisture.

(2) a subbase material somewhat capable of frost expansion when exposed to water, but also capable of serving as a source of free water to be drawn upon by contiguous frost-susceptible materials.

(3) base materials lacking adequate durability when exposed to freeze-thaw cycles in the presence of water or brine.

Recommendations

The investigation has indicated the following:

New construction

(1) Mixtures substantially more resistant to freezing-and-thawing deterioration in the presence of water and brine than the cement-aggregate and pozzolan-aggregate mixtures of the Stevenson Expressway should be selected for use in shoulder bases.

(2) Structural designs should be revised to provide for a substantially more positive means for removal of surface water and brine entering the structure; or to provide a substantially more positive means of sealing against the entrance of surface water and brine; or both.

Existing construction

(1) Steps should be taken to improve drainage of existing aggregate subbases.

(2) The longitudinal separation between pavement and shoulder, shoulder cracks, and pavement joints should be sealed against the entrance of surface water and brine by the most positive means at hand.

Experimentation

The value of the present investigation has been limited by a lack of adequate knowledge of many details regarding conditions prevailing prior to the occurrence of the shoulder displacement and deterioration. Before remedial measures can be applied with the desired degree of confidence, more information is needed on the relative effects that each of the factors of influence has in the development of such conditions as occurred on the Stevenson Expressway. For example, more needs to be known about the expansive characteristics of embankment soils compacted to the required density but subjected to a drying environment prior to covering. Experimentation that begins at the design stage and follows through the construction and service stages should be conducted to provide this information. This experimentation should be applied to the materials of construction as well as to structural design.

INTRODUCTION

Interstate Route 55 entering Chicago from the southwest (Stevenson Expressway) is a major artery of travel serving high volumes of traffic. An important 16 1/2-mile segment of this highway beginning in Cook County near the Cook-DuPage County line and extending to the Dan Ryan Expressway (I-90-94) in Chicago was constructed during the years 1963 and 1964, and formally opened to traffic on October 24, 1964.

The expressway consists of dual three-lane portland cement concrete pavements separated by a median of variable width. Both inside and outside shoulders are surfaced to a 10-foot width with bituminous concrete.

The topography of the general area varies from level to gently rolling. The southwestern three miles of the expressway lie on till sheets of the Valparaiso and Tinley moraines, with the remainder being on soils that were formed by the action of glacial Lake Chicago. A few cuts were made in the southwestern portion of the construction, but the remainder involves embankment. The soils are primarily fine-grained and fairly plastic.

The concrete pavement is of continuously-reinforced construction (steel ratio 0.6 per cent), except on the westernmost construction section where conventional distributed reinforcement and transverse joints at 100-foot intervals were used.

The pavement subbase was constructed of a well-graded crushed stone (Illinois Grade 8), 6 inches in thickness, and extended through the shoulder areas to the sod cover of the side slopes on all but the westernmost of the several construction sections into which the construction work was divided. On this single section that was the exception, the subbase was constructed with the width limited to a foot wider than the pavement on each side. The limited-width subbase was used at ramp locations on all construction sections.

Three kinds of material were used in the shoulder base courses: (1) cement-aggregate mixture (CAM); (2) pozzolan-aggregate mixture (PAM); and (3) bituminous-aggregate mixture (BAM). Base courses were constructed 7 1/2 inches in thickness and surfaced with 2 1/2 inches of bituminous concrete. The shoulder-base mixtures were placed on the crushed-stone subbases except for the single construction section where the subbase was extended only a foot beyond the pavement edge. On this section, the interior one foot of base rested on subbase, with the remainder resting on the natural embankment soil.

The location of the construction work in question is shown in Figure 1. Some general information regarding the construction is tabulated in Table 1. Typical cross sections are shown in Figure 2.

In late November 1964 the paved shoulders, which had been constructed at or slightly below the level of the adjoining pavement, were becoming generally higher than the pavement. The shoulder rise was accompanied frequently by longitudinal cracking of the shoulder surfaces parallel to, and within about a foot of the pavement edge. Horizontal separation of pavement and shoulder was common.

By January 1965, elevation differences between pavement and shoulder of over an inch were not infrequent. The formation of longitudinal cracks near the pavement edge had increased, and further cracking of the portion of the shoulder surface between the longitudinal cracks and the interface between pavement and shoulder had taken place at many locations. The high shoulders were obstructing drainage by

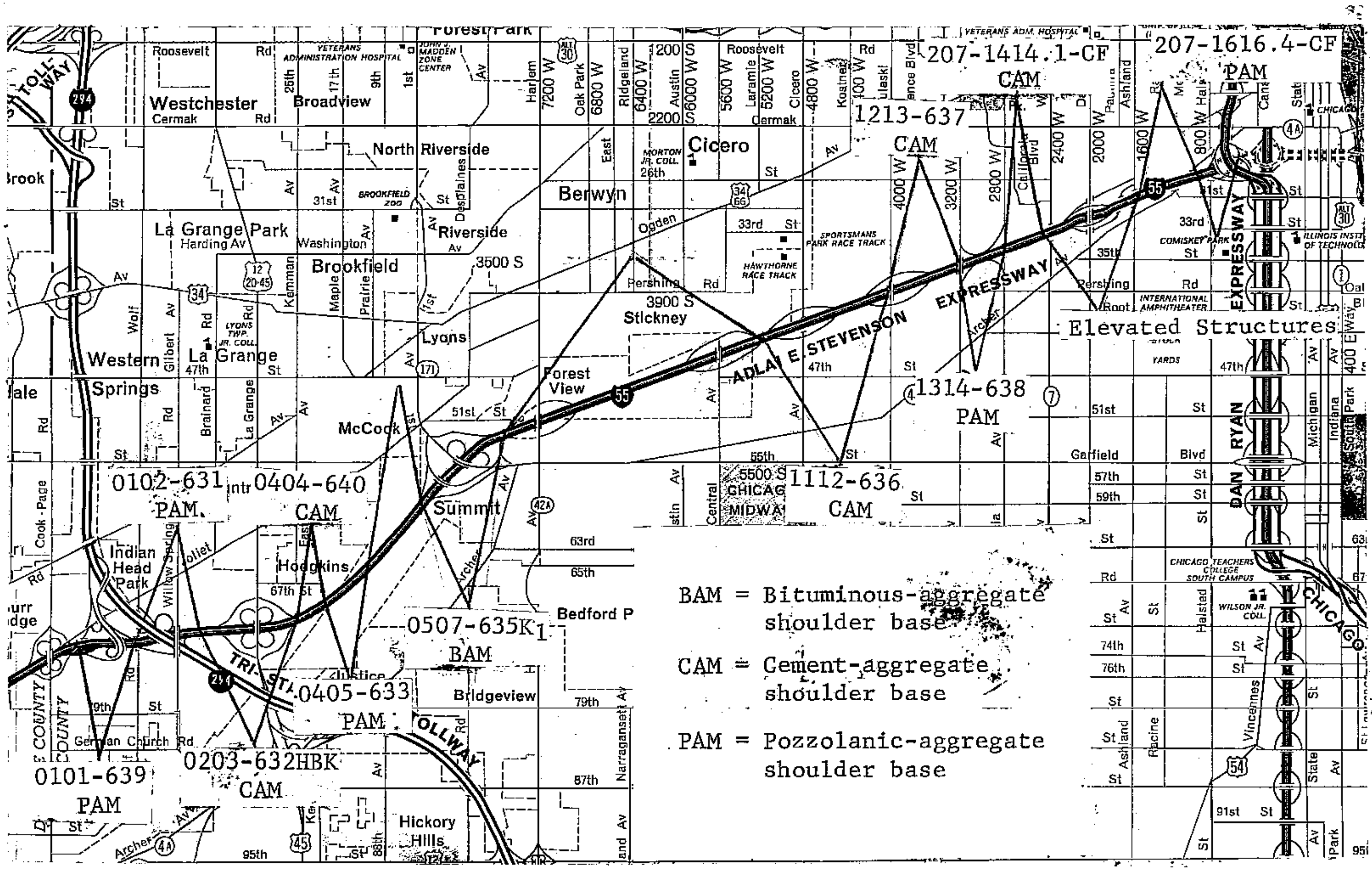


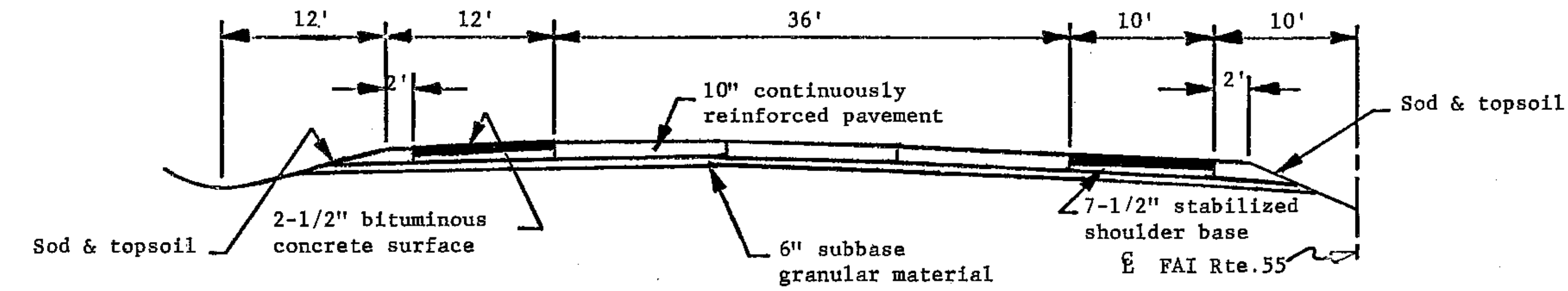
Figure 1. Stevenson Expressway location of paved shoulder investigation

TABLE 1

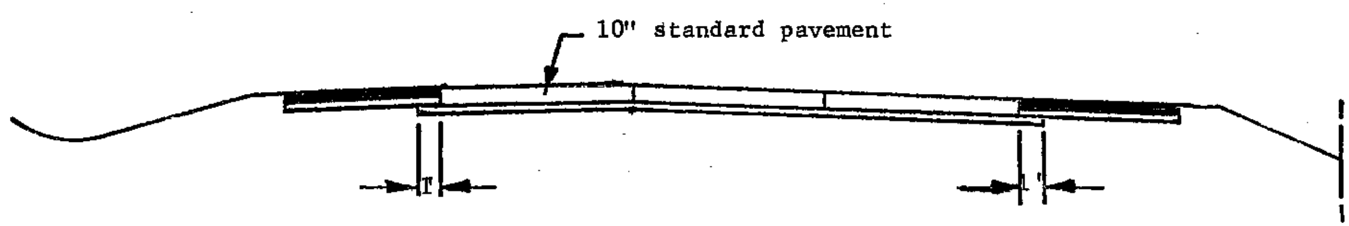
GENERAL INFORMATION

Construction Section	Length (miles)	Location: From	Location: To	Pavement Design 1/	Subbase: Type 2/	Subbase: Width	Shoulders: Base Type 3/	Shoulders: Base Thickness (in.) 4/
0101-639	0.5671	Joliet Road	Wolf Road	10" SRCP	Grade 8	Pvm't. + 2'	PAM	7 1/2
0102-631	0.8813	Wolf Road	E. of Willow Springs Rd.	10" CRCP	"	Shldr. to Shldr.	PAM	"
0203-632HBK	0.9279	E. of Willow Springs Rd.	W. of C & IW RR	"	"	"	CAM	"
0404-640	0.6736	C & IW RR	DesPlaines River	"	"	"	CAM	"
0405-633	0.9577	DesPlaines River	E. of Des Plaines River	"	"	"	PAM	"
0505-634	1.0083	E. of DesPlaines River	E. of B & OCT RR	"	"	"	PAM	"
0507-635K	3.8352	B & OCT RR	W. of Harlem Ave.	"	"	"	BAM	"
207-0711.2	3.0461	W. of Harlem Ave.	E. of Cicero Ave.	"	"	"	PAM	"
1112-636	1.5108	E. of Cicero Ave.	Pulaski Rd.	"	"	"	CAM	"
1213-637	1.1032	Pulaski Rd.	Kedzie Ave.	"	"	"	PAM	"
1314-638	0.5895	Kedzie Ave.	Calif. Ave.	"	"	"	PAM	"
207-1414.1-CF	0.2253	Calif. Ave.	W. End of Elevated	"	"	"	CAM	"
Elevated Structures 5/	1.4789	E. of Calif. Ave.	Chicago River					
207-1616.4-CF	0.9834	Chicago River	Halsted St.	10" CRCP	Grade 8	Shldr. to Shldr.	PAM	7 1/2
SW-1717.6-1P	0.3852	Halsted St.	FAI 94	"	"	"	CAM	"

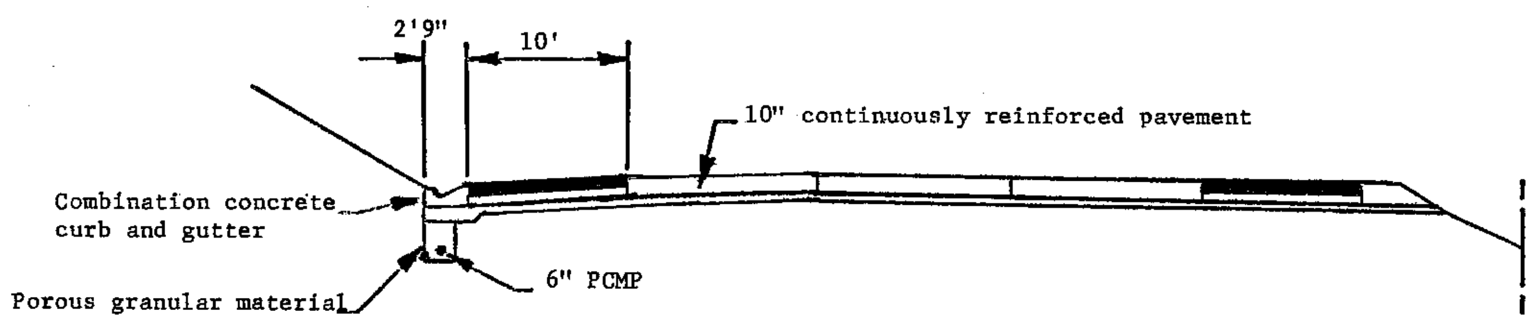
1/ SRCP = standard reinforced concrete pavement; CRCP = continuously reinforced concrete pavement
2/ Illinois Grade 8 crushed stone
3/ CAM = cement-aggregate mixture; PAM = pozzolan-aggregate mixture; BAM = bituminous-aggregate mixture
4/ Surfaced with 2 1/2 inches of bituminous concrete
5/ Elevated Structures - Sections 207-1414.1-CF, 207-1415.2-CF, 207-1415.3-CF, 207-1515.4, 207-1515.2-CF, 207-1516.2-CF, 207-1616.6-CF.



Cross Section for Continuously Reinforced PCC Pavement with Shoulder to Shoulder Subbase

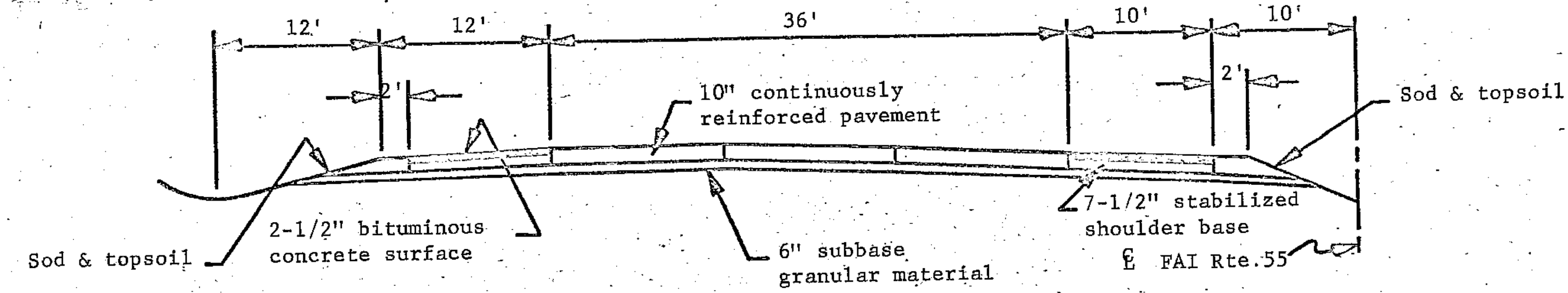


Cross Section for Standard Reinforced PCC Pavement with Limited-Width Subbase

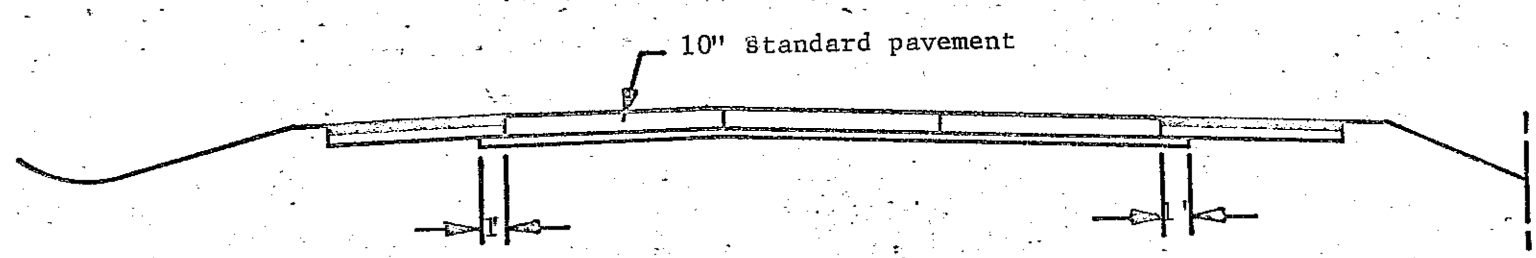


Cross Section for Continuously Reinforced PCC Pavement with Longitudinal Underdrains

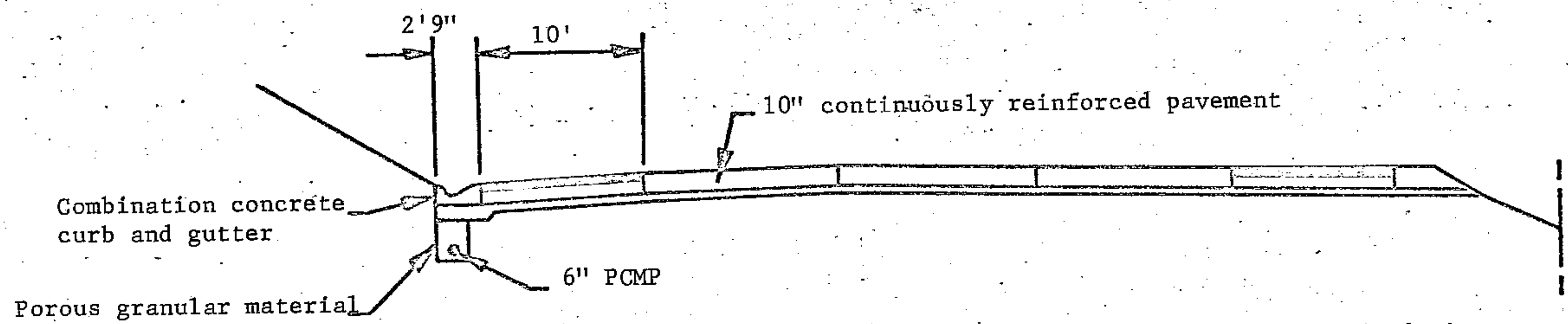
Figure 2. Typical cross sections



Cross Section for Continuously Reinforced PCC Pavement with Shoulder to Shoulder Subbase

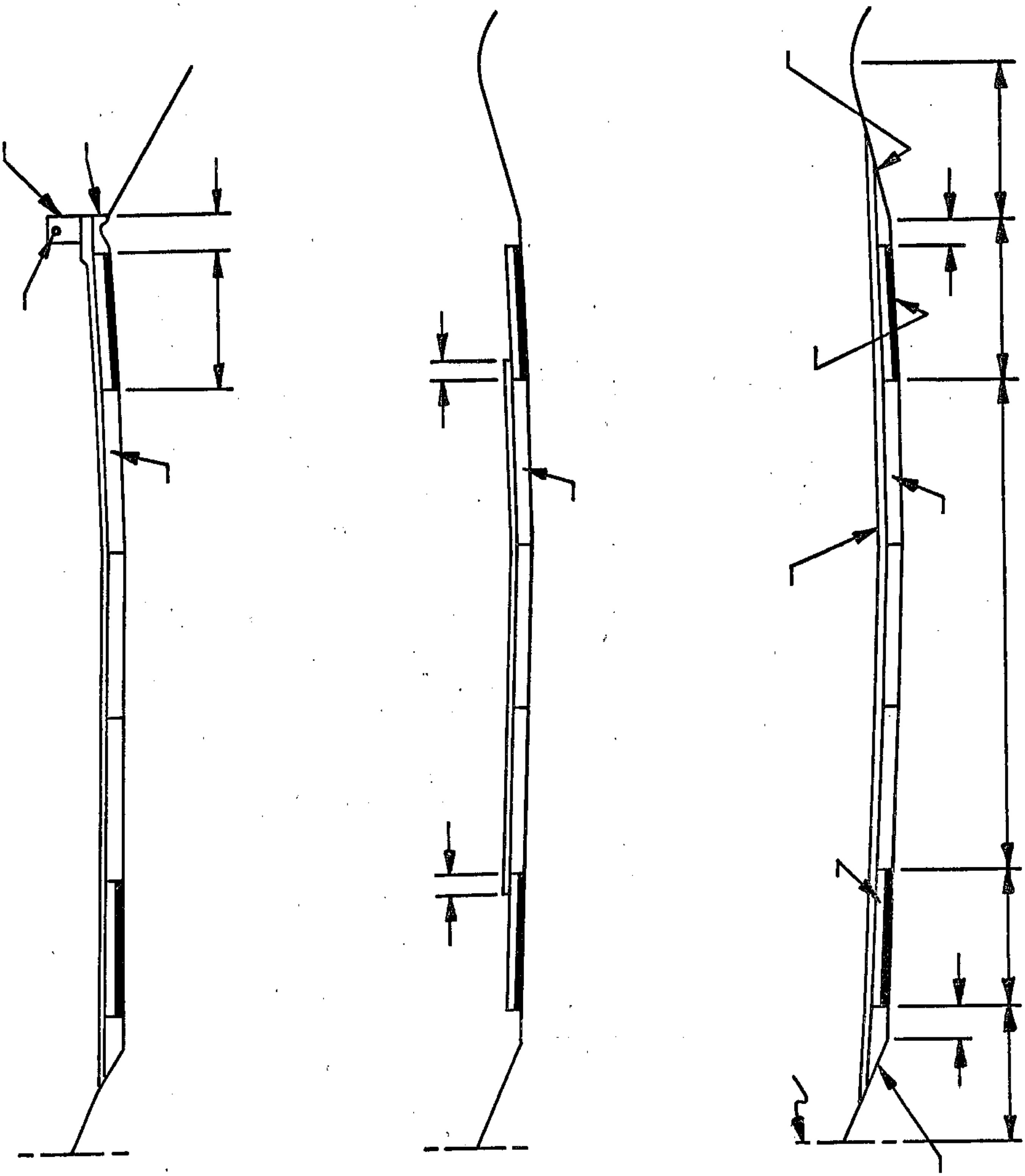


Cross Section for Standard Reinforced PCC Pavement with Limited-Width Subbase



Cross Section for Continuously Reinforced PCC Pavement with Longitudinal Underdrains

Figure 2. Typical cross sections



trapping water and often a potentially damaging solution of deicing salts and water at the pavement edges.

Bituminous paved shoulders were relatively new in Illinois at the time of their use on the Stevenson Expressway, having been adopted only a short time previously in an effort to overcome difficulties being experienced by aggregate shoulders both with and without bituminous surface treatments. These latter shoulder types had been found to lack stability in wet weather and to settle dangerously below pavement edges.

An inspection of the short mileage of paved shoulders in existence at the time at other locations in the State showed performance ranging from good to poor, and established that the deficiency of the shoulders of the Stevenson Expressway was not entirely unique except perhaps in degree of severity.

It was obvious that the paved shoulders, while correcting defects present in other shoulder types, were suffering from other and perhaps equally serious defects.

The study that is the subject of this report was made to gain a clearer understanding of the conditions associated with the movement and deterioration of paved shoulders, in order to provide a basis for the development of both remedial measures for improving the service of existing shoulders and improved designs for future construction.

The Stevenson Expressway was selected for the study because it appeared to offer special opportunity for the examination of the relative influences of the variables involved. Of prime interest was the presence of the three different shoulder base course mixtures (CAM, PAM, and BAM). Information regarding the compositions and sources of these mixtures is presented in Tables 2 and 3. The composition and density controls specified for PAM and CAM were those which would provide a dense, stable mixture with a minimum required strength. It was believed at the time that materials meeting the strength requirements also would have adequate freeze-thaw resistance. The BAM specification limits were set to provide a dense, stable mixture at a lower cost than a high-type bituminous concrete.

TABLE 2

SHOULDER BASE MIXTURES

Construction Section	Cementing Agent (% of total wt.)		Aggregate	Mixture Density: Field Density (% std. max.)	Mixture Density: Specification (% std. max.)	Material Sources		
Cement-Aggregate Mixture								
	Cement					Cement		Aggregate
0202-632HBK	4.5		Grade 8	96.5 - 104.8	94	Marquette		Dolese & Shepherd
0404-640	4.5		"	97.3 - 108.9	94	Marquette		Dolese & Shepherd
1112-636	4.5		"	99.7 - 102.5	94	Alpha		Materials Service (Stearns Quarry)
1213-637	4.5		"	97.1 - 102.6	94	Marquette		Consumers
207-1414.1-CF	-		"	- -	100	-		Materials Service (Stearns Quarry)
SW-1717.6-1P	5.0		"	95.7 - 105.3	95	-		Materials Service (Stearns Quarry)
Pozzolan-Aggregate Mixture								
	Lime	Flyash				Lime	Flyash	Aggregate
0101-639	4.3	12.0	Grade 8	94.8 - 103.2	100	Marble Head Lime Co.	Chicago Fly Ash Co.	Consumers
0102-631	4.5	12.0	"	99.3 - 102.5	100	"	"	"
0405-633 1/	4.5	12.0	"	95.6 - 105.0	100	"	"	"
0505-634	4.3	12.0	"	100.0 - 110.5	100	"	"	"
207-0711.2	4.3	12.2	"	99.9 - 108.1	100	"	"	"
1314-638 2/	4.3	28.0	Boiler Slag	99.6 - 101.8	100	Union Carbide Co.	"	Pozzolan Products Co. Inc.

TABLE 2 (CONTINUED)

1314-638[2]	4.3	12.0	Grade 8	99.8 - 102.2	100	Marble Head Lime Co.	Chicago Fly Ash Co.	Consumers
207-1616.4-CF	4.0	12.2	"	101.0 - 106.3	100	"	"	"
				Bituminous-Aggregate Mixture				
	Asphalt						Asphalt	Aggregate
0507-635K Part I	3.6		Grade 8	87.8 - 94.0	85		Trumbull Asphalt Co.	Dolese & Shepherd
0507-635K Part I	4.2		"	91.7 - 94.8	85		Seneca Petroleum Co.	Consumers

TABLE 3

SHOULDER BASE MIXTURE AGGREGATES

Construction Section	Aggregate	Typical Gradation - Passing Sieve 1 in. (%)	1/2 in. (%)	3/8 in. (%)	No. 4 (%)	No. 8 (%)	No. 10 (%)	No. 40 (%)	No. 200 (%)
Cement-Aggregate Mixture									
0202-632HBK	Grade 8 Cr. stone	100	83		50	36			7
0404-640	"	100	81		50	30			6
1112-636	"	100	76		50	34			7
1213-637	"	100	81		52	31			7
207-1414.1-CF	"	100	77		43	30			5
SW-1717.6-1P	"	100	81		42	25			6
Pozzolan-Aggregate Mixture									
0101-639	Grade 8 Cr. stone	100	85		54	32			7
0102-631	"	100	78		53	31			7
0405-633[1]	"	100	74		50	39			7
0505-634	"	100	83		54	33			7
207-0711.2-[illegible]	"	100	84		53	13			5
1314-638[2]	Boiler Slag			100			79	10	2
1314-638[2]	Grade 8 Cr. stone	100	68		35	26			8
207-1616.4-CF	"	100	82		49			13	4
Bituminous-Aggregate Mixture									
0507-635K Part I	Grade 8 Cr. stone	100	77		43	30			9
0507-635K Part I	"	100	79		57	41			10

1/ Small amount of CAM used on this section for hand work after time limitation for PAM.
2/ Median shoulders have wet bottom boiler slag as aggregate and outside shoulders have Grade 8 as aggregate.

The study included both field and laboratory investigations. In the field, detailed observations of surface conditions and measurement of shoulder displacement were made on short sections of shoulder selected to represent conditions on each construction section. Subsurface conditions were examined by the removal of cover and by other means of exposing underlying materials. Numerous laboratory tests were conducted on cores and other materials removed during the subsurface examinations. Information on related subjects conceived to be of influence such as air temperature, precipitation, frost penetration, and deicing salt application during the period of and immediately preceding the study was also obtained and examined.

FIELD INVESTIGATION

The field investigation began in February 1964 with the selection from each construction section of shorter sections for detailed study. A total of 35 research study sections were selected from 14 construction sections. Each study section included one shoulder, either outside or median, and either in the eastbound or westbound roadway. The final selection included seven westbound outside shoulders, ten westbound median shoulders, ten eastbound outside shoulders, and eight eastbound median shoulders.

Most of the study sections were established at a 1000-foot length; however, a few somewhat shorter sections were chosen when necessity required that they be fitted between closely spaced bridges.

The original intent in the selection of the research study sections was to choose one to represent the best conditions on a construction section and the other to represent the poorest. In laying out the sections in the field, however, it was found that shoulder conditions were often fairly uniform throughout individual construction sections, making difficult the selection of 1000-foot sections of distinctly different appearance. The best possible effort was applied in an attempt to make the choice as originally planned, but when mapping details became available it was found that for many of the construction sections little difference was shown between conditions on the study sections initially selected to represent the best and those selected to represent the poorest.

Locations and other pertinent features of the research study sections are recorded in Table 4.

Field Survey Procedures

In February 1965, and again in May 1965, distress conditions, as indicated by cracks and broken areas, were mapped for each of the research study sections. Vertical differentials in elevation between pavement and shoulder were measured with a straightedge at 100-foot intervals. Horizontal separations between pavement and shoulder were measured with sufficient frequency that the approximate footage at various openings differing in 1/4-inch increments could be estimated.

Level readings were taken with an engineer's level at three equally spaced locations in each study section in February and May 1965, and more frequently in a few of the sections. Benchmarks were established on bridge abutments, culvert headwalls, and survey markers placed during construction. Readings were taken at the outer edge, midwidth, and inner edge of the shoulder, and at the adjoining edge of the pavement and 12 feet onto the pavement.

Cores were taken, excavations were made, and other work was done to investigate below-surface conditions.

Surface Distress

The number of transverse cracks and the square feet of "area distress" observed in each of the test sections during the February and May 1965 field surveys are tabulated in Table 5. The identification "area distress" applies to those areas where cracks are of a random nature and too closely spaced to map separately. Almost all of these areas are located between the pavement edge and the longitudinal crack typically formed parallel to and about a foot away from the interface of shoulder and pavement. The remaining few such areas are located at the outer edge of the shoulders. The transverse cracks were very similar to those seen in unreinforced

TABLE 4

LOCATION OF RESEARCH STUDY SECTIONS

Construction Section	Shoulder Base Type	Research Study Section	Station From	Station To	Section Length (ft.)	Shoulder Location	Remarks
0101-639	PAM	1	1114+00	1124+00	1000	WB Median	Shoulder base on subgrade soil
		2	1127+00	1137+00	1000	WB Median	"
		3	1116+50	1126+50	1000	EB Median	"
0102-631	PAM	4	1168+40	1178+40	1000	WB Outside	Longitudinal Underdrains at outer edge of shoulder-to-shoulder subbase
		5	1161+00	1171+00	1000	EB Outside	"
		6	1168+40	1178+40	1000	WB Median	Shoulder-to-shoulder subbase
0203-632HBK	CAM	7	129+40	139+40	1000	WB Outside	Shoulder base on subgrade soil
		8	129+40	139+40	1000	WB Median	Shoulder-to-shoulder subbase
		9	151+60	161+60	1000	WB Median	"
0404-640	CAM	10	180+00	187+54	754	EB Outside	"
		11	180+00	188+46	846	EB Median	"
0405-633	PAM	12	189+00	199+00	1000	WB Outside	"
		13	189+00	199+00	1000	WB Median	"
		14	186+00	196+00	1000	EB Outside	"
0505-634	PAM	15	249+00	259+00	1000	EB Outside	"
		16	249+00	259+00	1000	EB Median	"
		17	249+00	259+00	1000	WB Median	"
0507-635K Part I	BAM	18	292+00	302+00	1000	EB Outside	"
		19	324+00	334+00	1000	EB Outside	"
207-0711.2	PAM	20	529+50	539+50	1000	EB Outside	"
		21	547+50	557+50	1000	EB Median	"
		22	573+50	583+50	1000	WB Outside	"
		23	573+50	583+50	1000	WB Median	"
1112-636	CAM	24	26+20	36+20	1000	EB Outside	Shoulder base on subgrade soil
		25	26+20	36+20	1000	EB Median	Shoulder-to-shoulder subbase

TABLE 4 (Cont.)

1213-637	CAM	26	66+65	76+65	1000	EB Outside	Shoulder-to-shoulder subbase
		27	66+65	76+65	1000	EB Median	"
		28	114+00	124+00	1000	WB Outside	"
1314-638	PAM	29	137+00	147+00	1000	WB Outside	"
		30	137+00	147+00	1000	WB Median	"
207-1414.1-CF	CAM	32	2+00	12+00	1000	WB Outside	"
		33	2+00	12+00	1000	WB Median	"
207-1616.4-CF	PAM	34	210+30	219+12	882	EB Outside	"
		35	210+30	219+12	882	EB Median	"
SW-1717.6-1P	CAM	36	19+00	22+00	300	EB Median	"

portland cement concrete pavements, evidencing a nonductile facture probably caused, at least in part, by thermal contraction. Transverse cracking and area distress seemed mostly unrelated. In the few instances where the study sections were shorter than the planned 1000-foot length, the figures in Table 5 have been adjusted to place all on the 1000-foot basis.

It will be noted in Table 5, where test sections have been grouped according to type of shoulder-base construction, that transverse cracking and area distress are confined to sections involving CAM and PAM bases. Neither transverse cracking nor area distress was noted in the BAM sections.

It will be seen that a wide range in the frequency of transverse cracking was found in both the CAM sections and the PAM sections. Certain of the sections of both base types showed no transverse cracking in either of the surveys. Increases in transverse cracking between February and May were mostly moderate. Sections having the greatest frequency of transverse cracking were mostly in median shoulders, the reason for which is not clear.

A wide range in area distress also will be noted between sections, without a significant difference between CAM and PAM base sections. Certain of the sections of both base types showed no area distress. The tendency toward area distress to be of greater magnitude in the outside shoulders is believed to be the result of greater usage of the outside shoulders by traffic. This type of distress, which it will be recalled was found to have occurred mostly near the pavement edge, is thought to be accelerated by traffic usage.

No positive relationship between transverse cracking and area distress could be identified.

Rise of Shoulders Above Pavement Edge

Plan details of the shoulders of the Stevenson Expressway called for their construction at the same elevation of the pavement at the interface of shoulder and pavement. Field construction engineers throughout the State have been aware

TABLE 5

DISTRESS OF SHOULDER WEARING SURFACE

Shoulder Base Type	Shoulder Location	Research Section	February 1965 Transverse Cracks (no.)	February 1965 Area Distress (sq. ft.)	May 1965 Transverse Cracks (no.)	May 1965 Area Distress (sq. ft.)
CAM	Median	8	38	0	38	0
	"	9	21	613	23	727
	"	11*	0	390	0	430
	"	25	0	119	0	158
	"	27	5	43	7	48
	"	33	6	0	6	0
	"	36*	0	0	0	0
	Outside	7	1	1084	1	1689
	"	10*	0	771	0	773
	"	24	0	0	0	0
	"	26	0	160	0	167
	"	28	0	193	0	206
	"	32	10	7	10	113
PAM	Median	1	18	367	27	528
	"	2	23	29	23	33
	"	3	25	8	31	38
	"	6	10	318	11	331
	"	13	8	0	9	0
	"	16	0	0	0	0
	"	17	0	166	0	200
	"	21	12	58	18	93
	"	23	21	50	31	259
	"	30	0	0	1	0
	"	35*	2	436	7	595
	Outside	4	1	306	1	333
	"	5	12	220	12	225
	"	12	1	223	1	235
	"	14	23	0	24	16
	"	15	0	414	0	440
	"	20	2	350	3	391
	"	22	6	510	10	529
	"	29	0	273	0	405
	"	34*	9	330	9	538
BAM	Outside	18	0	0	0	0
	"	19	0	0	0	0

*Sections shorter than the standard 1000 ft.; survey figures projected to 1000-ft. length in table.

of the importance of providing positive drainage of the pavement, and have been careful not to allow shoulders to be constructed higher than the pavement. It can be presumed that this practice was observed in the construction of the Stevenson Expressway.

The widespread vertical movement that has placed the paved shoulders of the Stevenson Expressway (and paved shoulders elsewhere) at a higher elevation than the contiguous pavement is accepted to be an upward movement of the shoulders with reference to the pavement rather than downward movement of the pavement. Prior experience with the behavior of new widening strips and new pavements placed to abut old pavements that could be expected to have attained a measure of vertical stability, suggests this to be reasonable.

Averages of the measured vertical distances between pavement and shoulder at their interface in each study section have been tabulated for the February and May 1965 surveys in Table 6. Figures in all instances represent distances that the shoulders are higher than the pavements (except in three instances where a zero average was recorded). Average differentials will be seen to have been consistently greater at the time of the February survey as compared with the May survey, giving strong indication of a frost-heave involvement.

Study sections in areas of CAM and PAM shoulder base showed average elevation differentials between pavement and shoulder over a wide range varying from zero to in excess of an inch. Little difference is observable between the CAM and the PAM base sections, and between outside and median shoulders. The BAM base sections showed differential movement intermediate between the poorest and best CAM and PAM base sections. The shoulders had not returned to constructed levels at or slightly below the pavement surface at the time of the May survey. Later observations have shown a general tendency for them to remain higher than the pavement surface indefinitely.

To gain some knowledge of the daily vertical movements of shoulders, the differential between pavement and shoulder was measured daily during February and April

TABLE 6

RISE OF SHOULDERS ABOVE PAVEMENT EDGE

Shoulder Base Type	Shoulder Location	Research Section	Average Distance Above Pavement* (in.) February 1965	May 1965
CAM	Median	8	0.30	0.19
	"	9	1.04	0.61
	"	11	0.68	0.36
	"	25	0.39	0.25
	"	27	0.05	0.07
	"	33	0.36	0.01
	"	36	0.00	0.04
	Outside	7	0.17	0.10
	"	10	0.55	0.08
	"	24	0.07	0.00
	"	26	0.20	0.15
	"	28	0.30	0.09
	"	32	0.11	0.03
PAM	Median	1	0.36	0.30
	"	2	0.73	0.52
	"	3	0.55	0.19
	"	6	0.75	0.35
	"	13	0.55	0.17
	"	16	0.12	0.10
	"	17	0.45	0.53
	"	21	0.41	0.32
	"	23	0.32	0.15
	"	30	0.16	0.09
	"	35	0.05	0.00
	Outside	4	0.64	0.23
	"	5	0.51	0.27
	"	12	0.94	0.15
	"	14	0.59	0.11
	"	15	0.33	0.25
	"	20	0.32	0.03
	"	22	0.34	0.06
	"	29	0.64	0.14
	"	34	0.00	0.03
BAM	Outside	18	0.25	0.11
	"	19	0.43	0.15

*Measurements made with straightedge mostly at 100-ft. intervals

1965 at 30 locations in six research study sections. Following is a typical example of the readings that were obtained.

Research Study Section 9
Median Shoulder
Station 152+89

Date (Feb. 1965)	Differential Measurement (in.)	Date (Feb. 1965)	Differential Measurement (in.)
13	1.3	21	1.3
14	1.5	22	1.5
15	1.4	23	-
16	1.5	24	-
17	1.6	25	1.8
18	1.5	26	1.8
19	1.4	27	1.8
20	1.5	28	1.6

The daily readings indicate measureable daily fluctuations up to 0.2 inches during the period involved. These minor movements are probably the results of freeze-thaw activity and moisture change in the subgrade and shoulder components. No detailed exploration of the causes was made.

As mentioned earlier, level readings were taken across the shoulders in addition to the offset readings made with a straightedge to investigate vertical shoulder and pavement movements with reference to fixed markers. Readings were taken during February and May 1965 at three corss-sectional locations in each study section at the outer edge, midpoint, and inner edge of the shoulder, and at the adjoining pavement edge and 12 feet onto the pavement. In a few study sections, readings were taken more frequently than the February and May series.

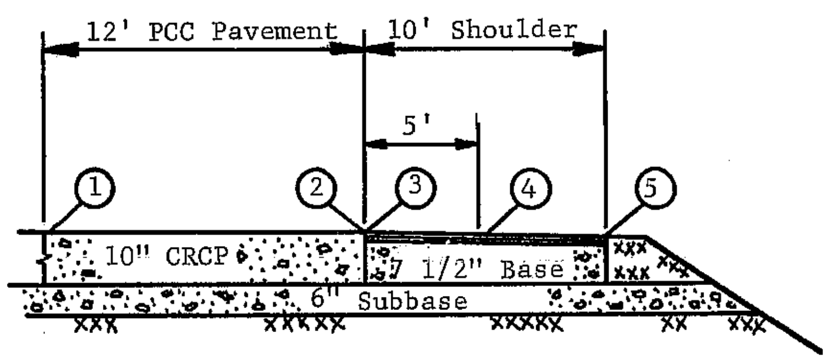
The information presented in Table 7 is typical of the considerable quantity of data obtained in the leveling study. It will be seen that the pavement and shoulder are both subject to vertical movement, and that downward movements of an inch and more are not uncommon following the winter season.

TABLE 7

CHANGES IN ELEVATION OF PAVEMENT AND
SHOULDER IN RESEARCH STUDY SECTION 9

Station	Location	Date of Elevation Reading				
		2-8-65	2-11-65	2-23-65	3-9-65	5-27-65
		(change in feet from initial reading)				
152+00	1	-	-	-0.01	-0.05	+0.02
	2	-	-0.04	-0.04	-0.09	-0.04
	3	-	-0.02	-0.04	-0.08	-0.08
	4	-	-0.01	-0.02	-0.08	-0.04
	5	-	-0.03	-0.02	-0.07	-0.03
155+00	1	-	-	-0.01	-0.08	-0.10
	2	-	-0.01	-0.02	-0.11	-0.11
	3	-	0.00	0.00	-0.10	-0.12
	4	-	+0.01	-0.02	-0.10	-0.13
	5	-	+0.01	0.00	+0.04	-0.09
158+00	1	-	-	+0.05	-0.03	-0.02
	2	-	-0.03	+0.01	-0.07	-0.06
	3	-	-0.03	+0.02	-0.06	-0.08
	4	-	0.00	+0.03	-0.08	-0.09
	5	-	-0.02	+0.04	-0.03	-0.03

Location of Readings on Typical Cross Section



No data are available on the vertical movements of the pavements and shoulders during the period following the completion of construction in the fall of 1964 and the initial elevation readings in February 1965. This and other information is needed for a full understanding of the processes involved in the vertical movements.

Research Study Sections 1, 2, 3, 7, and 24 involve shoulders in which the bases were placed directly on the embankment soil except for the small amount that the pavement subbase extends beyond the edge of the pavement. All other study sections involve shoulders in which the bases rest on the extension of the pavement subbase through the shoulder areas.

A comparison of the area distress and the distances of rise above the pavement surface of these shoulders with those on full granular subbase shows no distinct behavioral difference.

Study Section 4 involves a design that includes a longitudinal pipe underdrain immediately outside the shoulder area. This underdrain was installed in what was considered to be an area of high water table. Admittedly, conditions here are probably more severe than on the other sections of the study. However, it is noted that the underdrain was not effective in preventing shoulder surface distress and a rise of the shoulder above the pavement surface.

Area Distress as Related to Vertical Differential Movement

It seems reasonable to hypothesize that area distress is somehow related to the differential movement of the shoulders with respect to the pavement. Figure 3 has been prepared to assess this relationship, using the vertical movement differentials of the February survey and the areal extent of broken shoulder pavement recorded in the May survey. It will be noted from Figure 3 that the measurements made in the present study did not establish a clear relationship. This analysis was limited to the CAM and PAM shoulder bases for it will be recalled that no distress occurred in the BAM base.

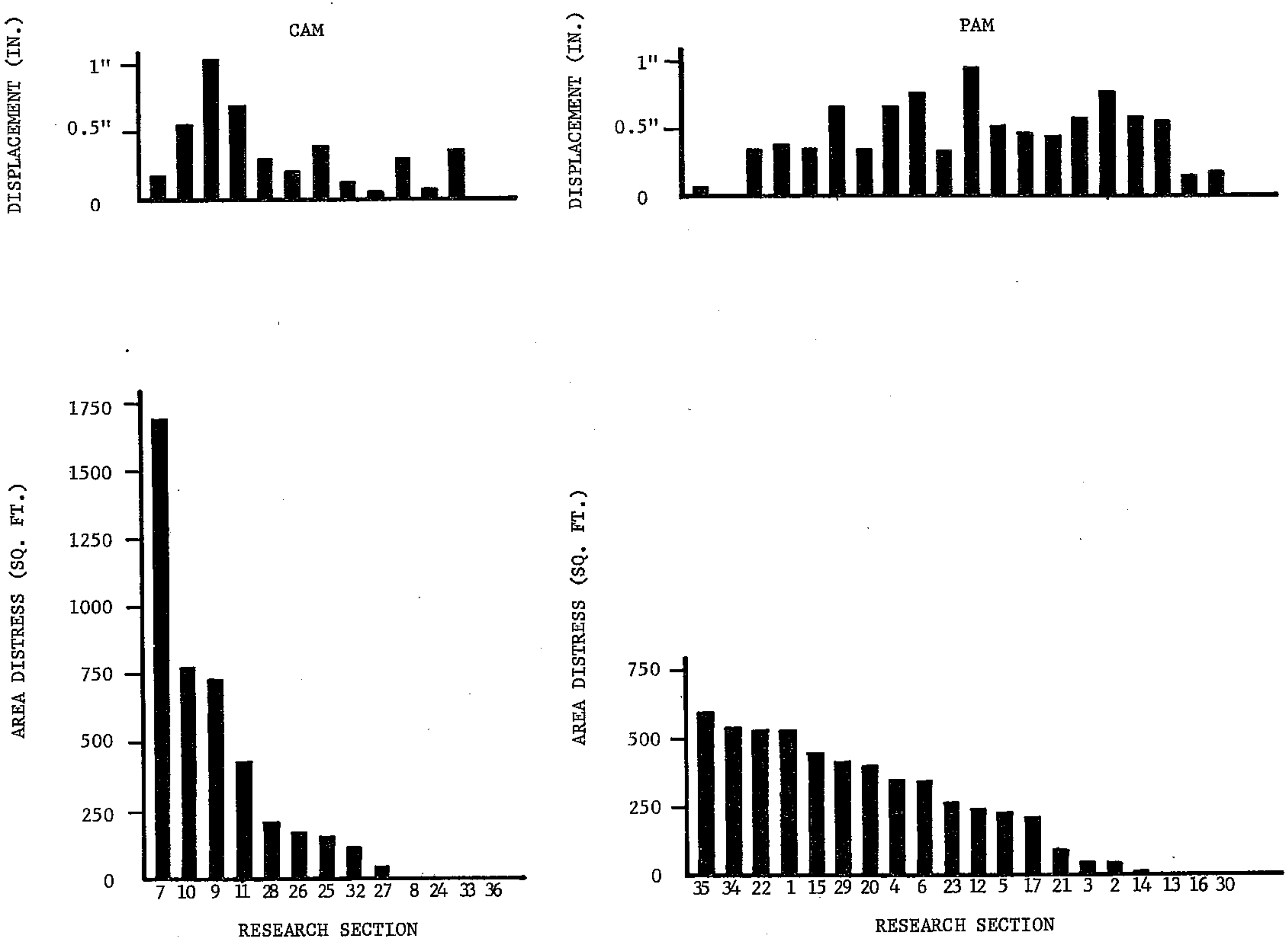


Figure 3. Area distress of paved shoulders as related to vertical displacement.

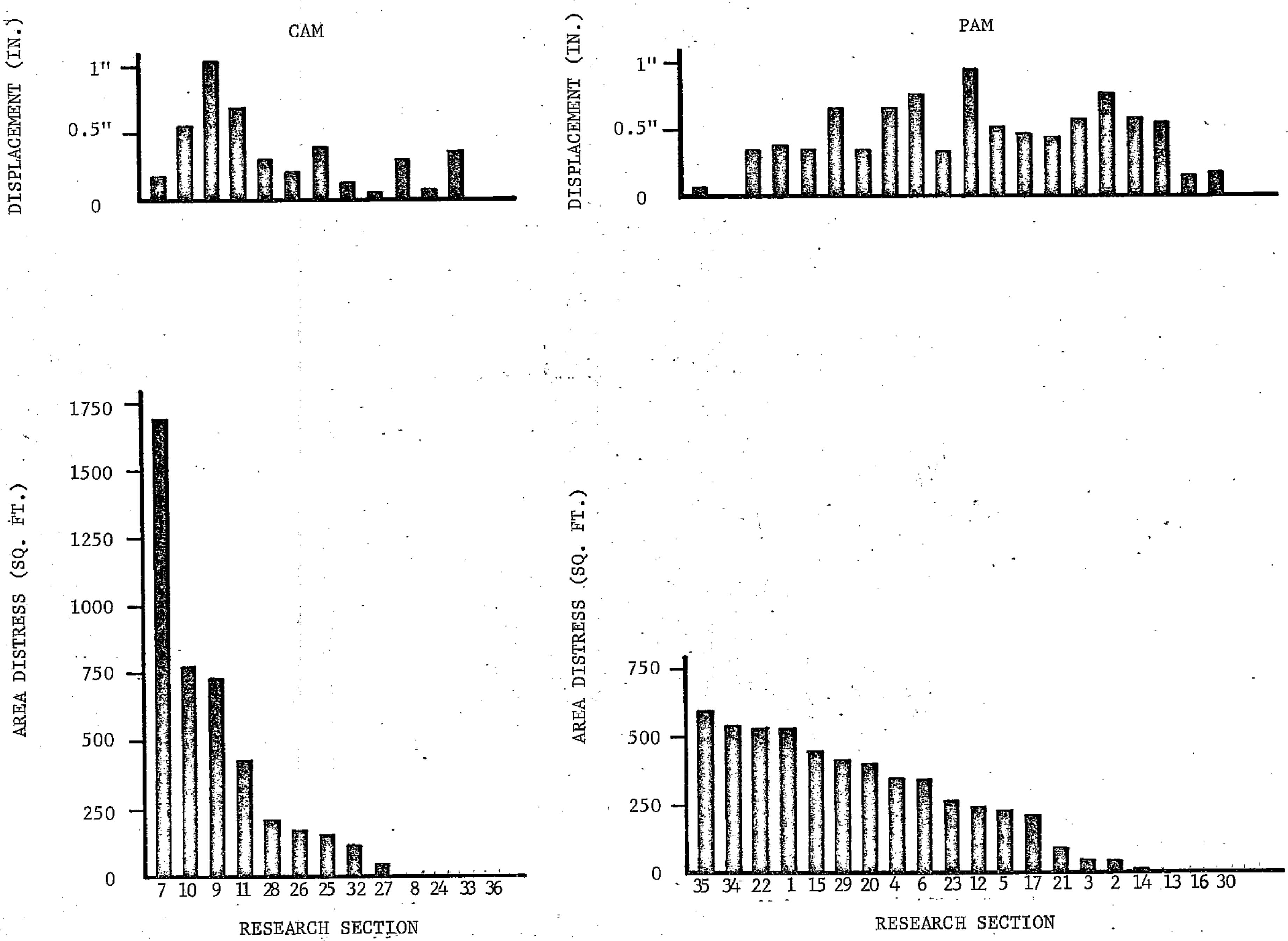
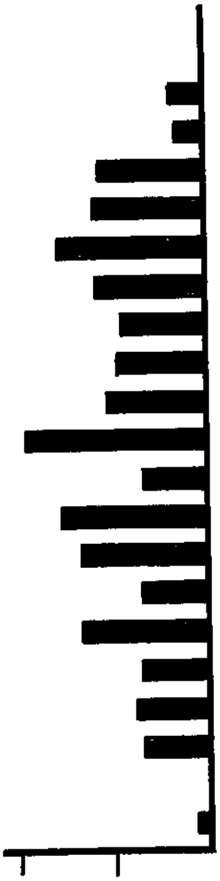
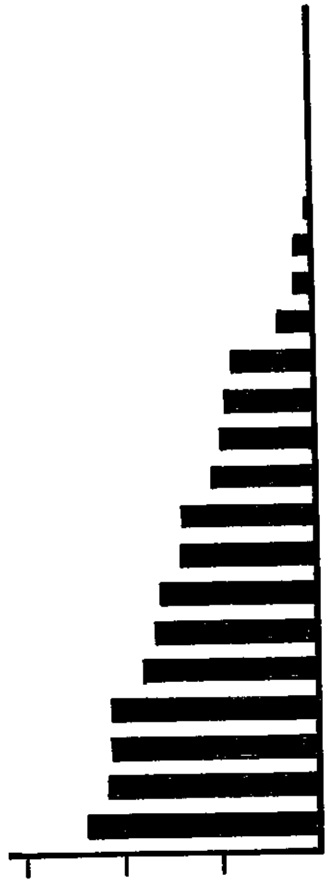
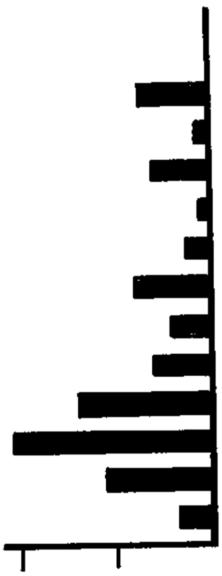
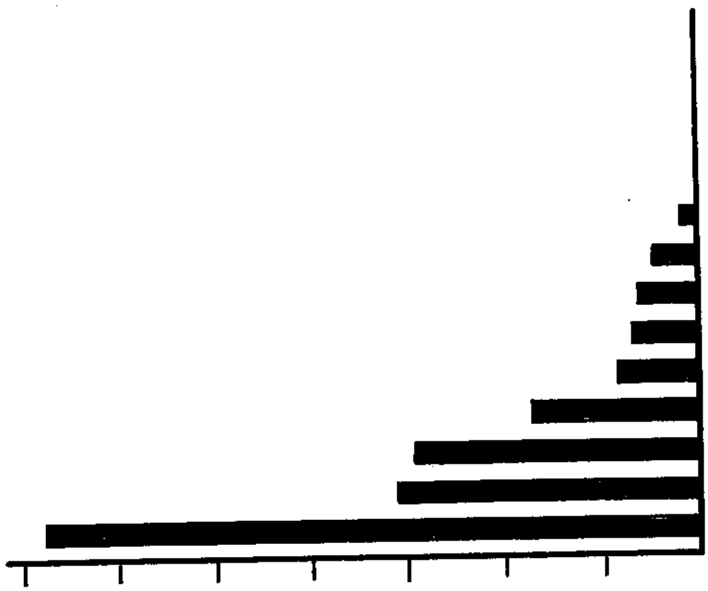


Figure 3. Area distress of paved shoulders as related to vertical displacement.









Separation of Shoulder and Pavement

Preliminary observations showed that the shoulders had become separated from the pavements throughout most of the length under consideration. During the field survey, measurements were made of the lateral displacement to permit an estimate of the lengths of shoulder separated by several degrees of separation. Table 8 has been prepared to summarize the results of the shoulder separation measurements. Four separation classes were established as a means for analyzing the separation data. They are: Class 1 - separation of less than 1/4 inch; Class 2 - separation of 1/4 inch to less than 1/2 inch; Class 3 - separation of 1/2 inch to less than 3/4 inch; and Class 4 - separation of 3/4 inch or more.

It will be noted in the table that the more severe degrees of separation were confined primarily to the CAM and PAM base sections, with the PAM base sections showing the greater amount of the more severe separation. No consistent trends were found between the severity of separation of outside shoulders and of median shoulders. It will be noted that the BAM base shoulders were not free of separation although the degree of separation was moderate.

Figure 4 was prepared to determine whether or not a relationship may exist between the severity of surface distress and the degree of shoulder separation. Figure 5 was prepared to determine whether a relationship exists between the amount of vertical displacement of the shoulders and shoulder separation. It will be noted that no clear relationships could be established from Figures 4 and 5.

The shoulder separation data summarized in Table 8 are for the February 1965 survey. Measurements made in May 1965 indicated that a considerable amount of closure of the separation took place until no openings of 1/4 inch and wider existed at that time except on one study section (Research Study Section 10).

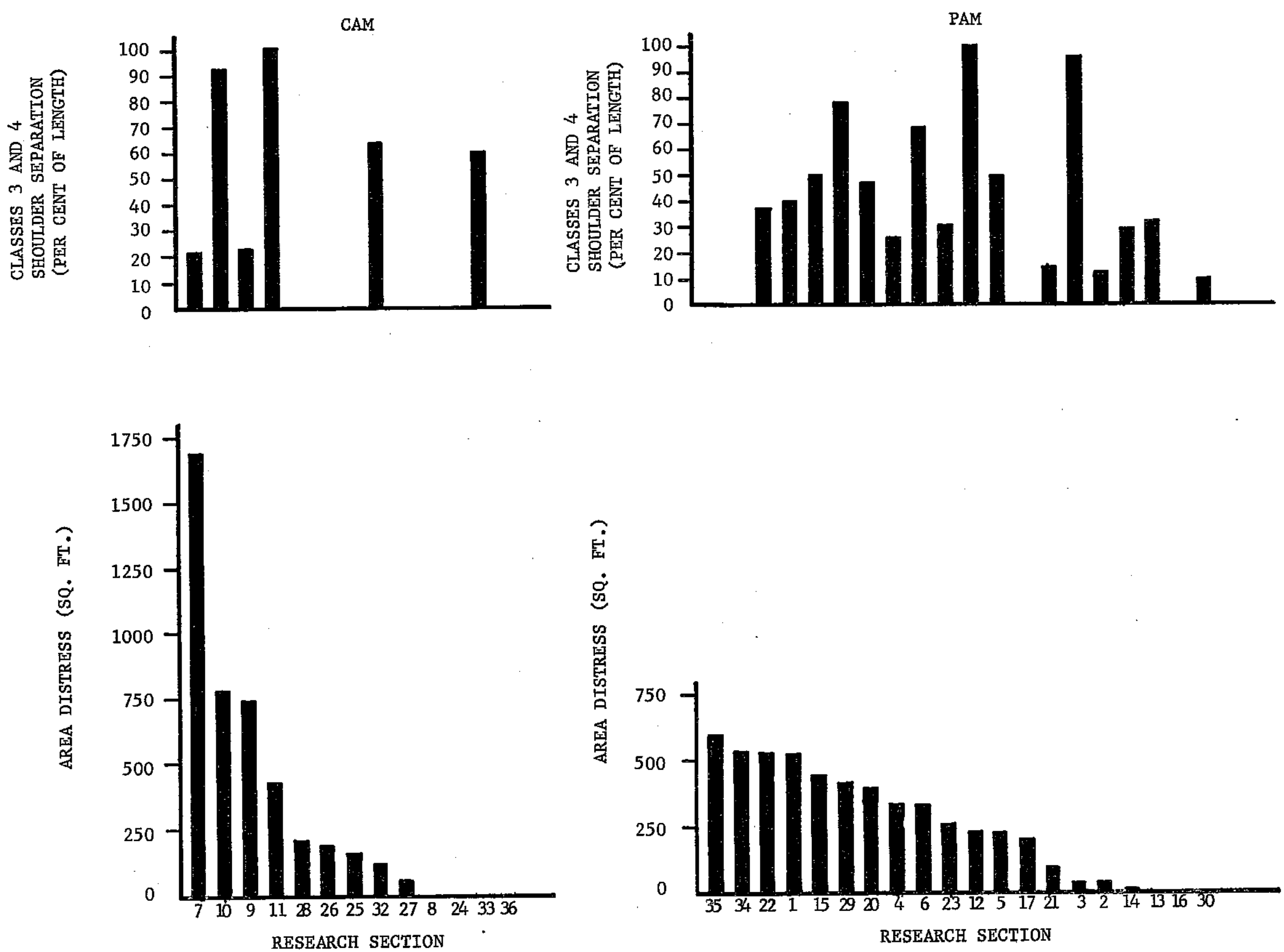


Figure 4. Area distress of paved shoulders as related to shoulder separation.

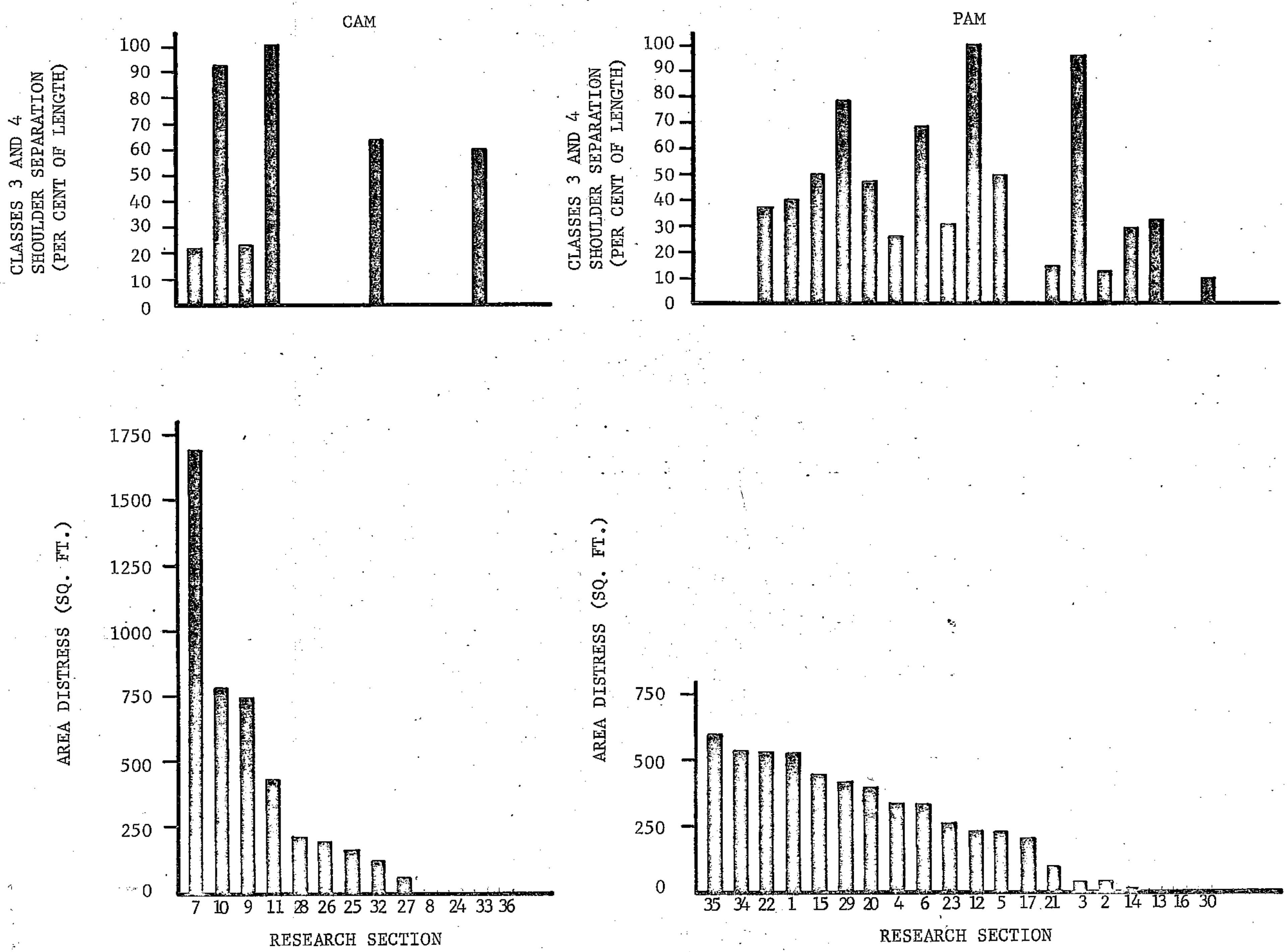
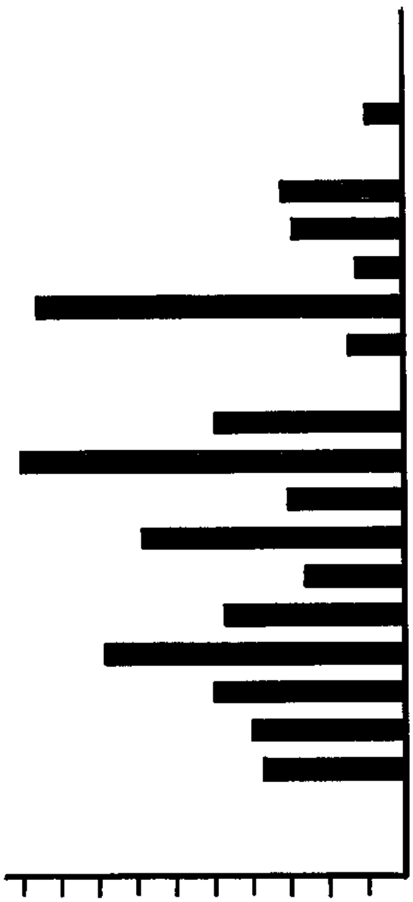
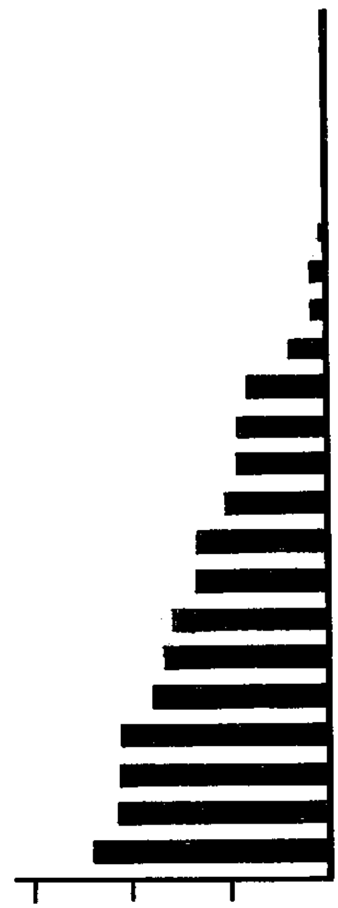
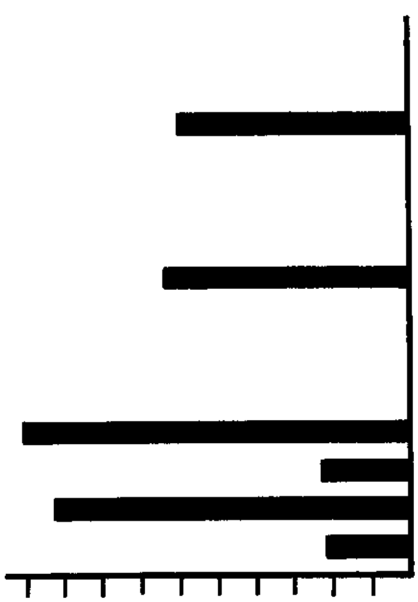
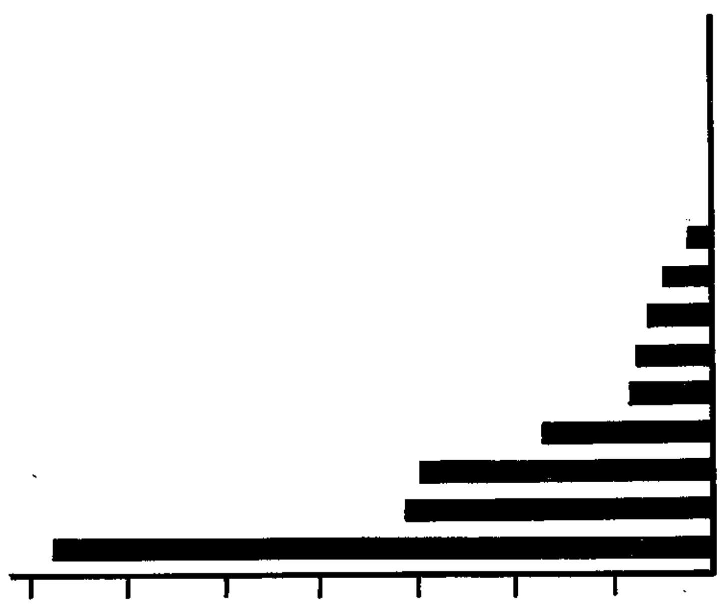


Figure 4. Area distress of paved shoulders as related to shoulder separation.









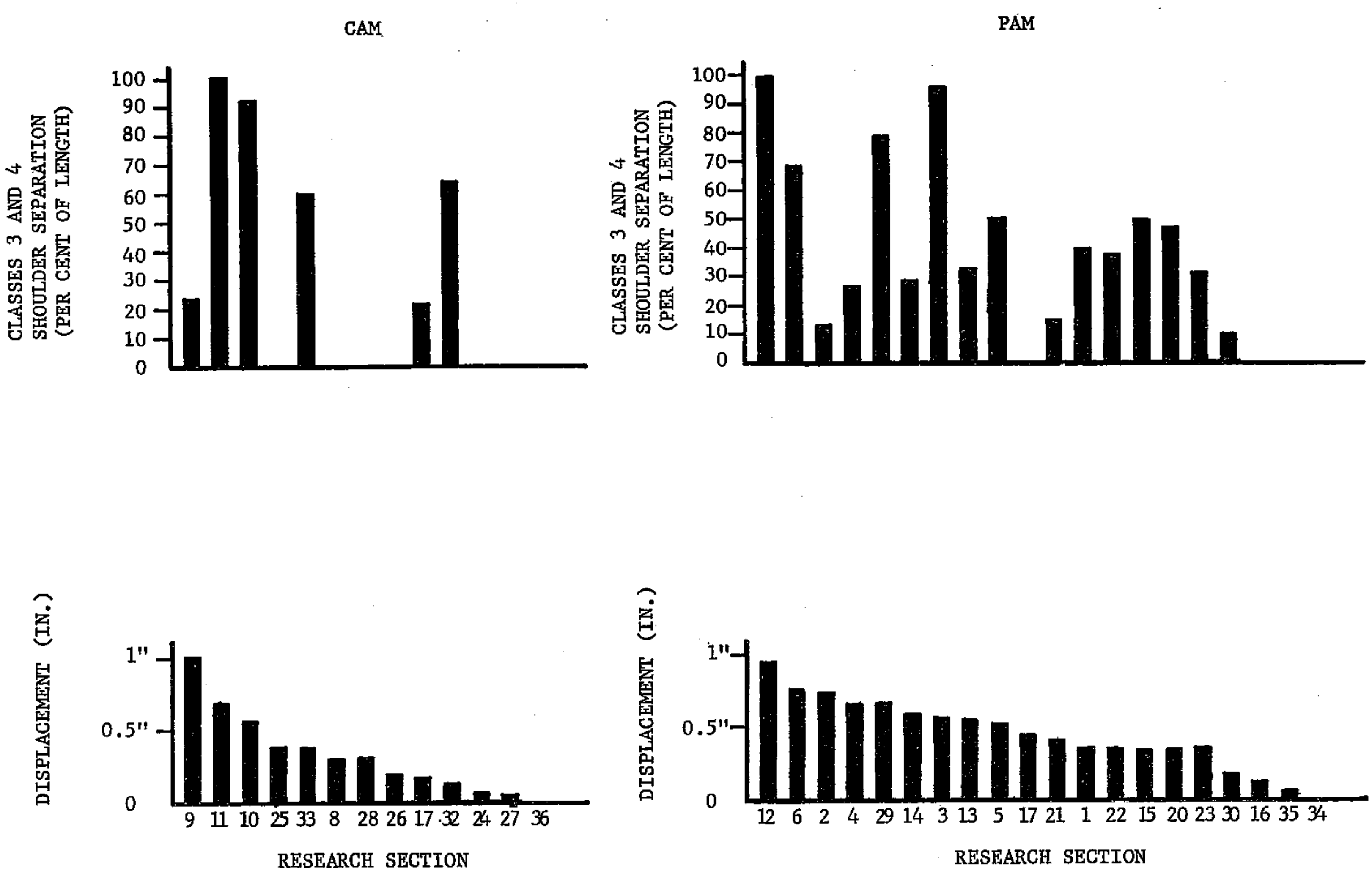


Figure 5. Vertical displacement of shoulders as related to shoulder separation.

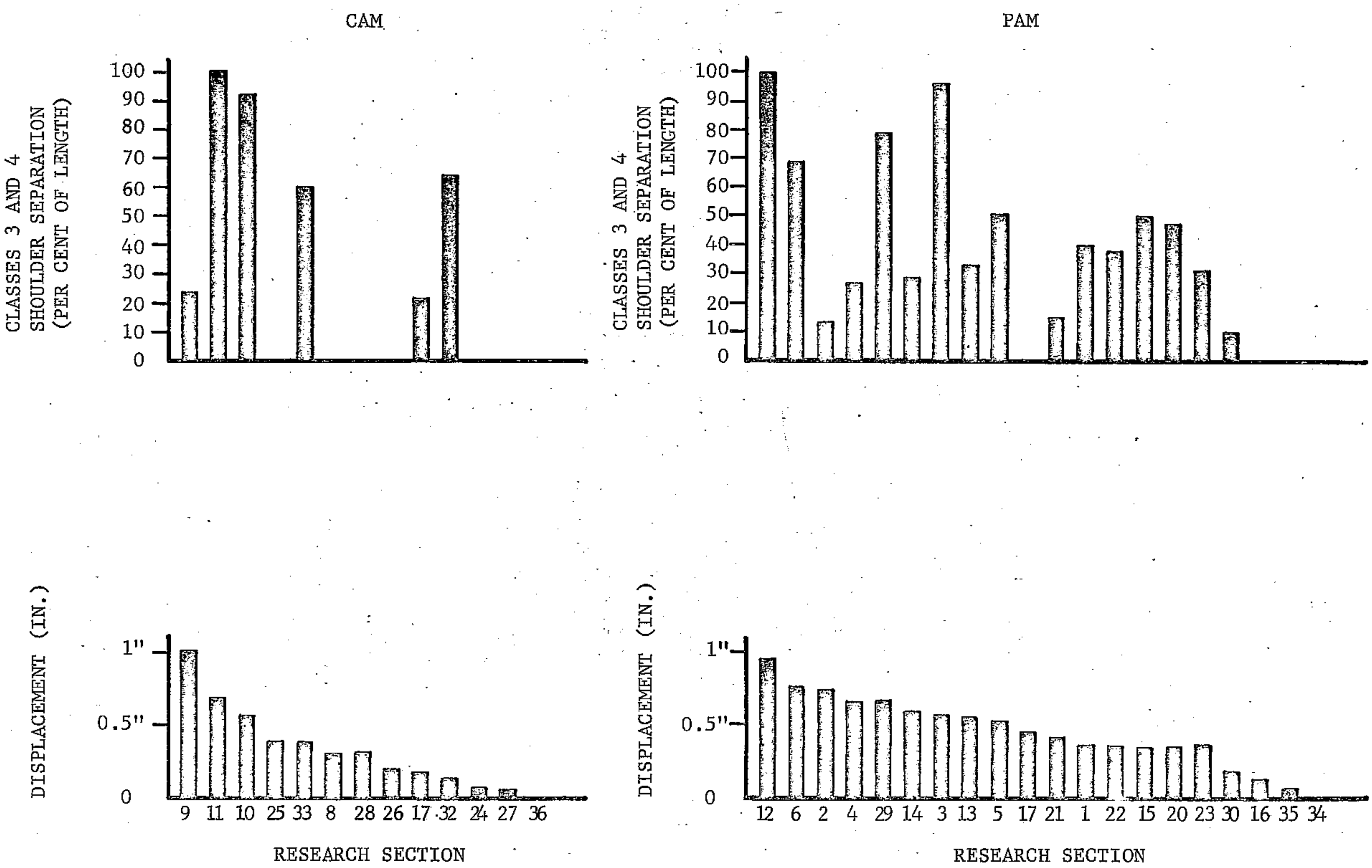


Figure 5. Vertical displacement of shoulders as related to shoulder separation.

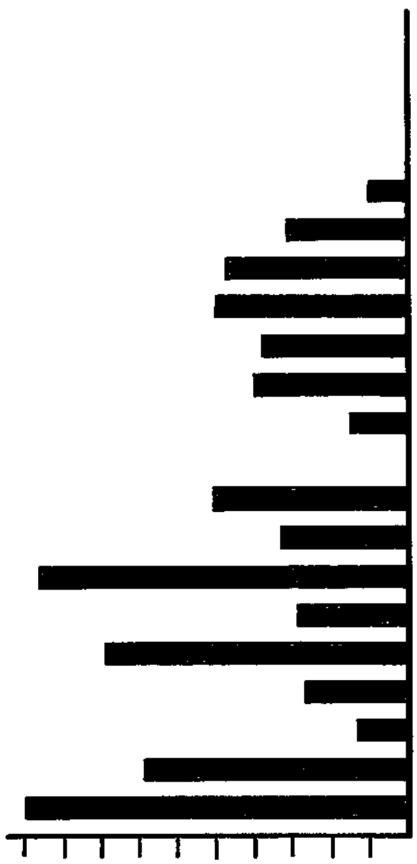


TABLE 8

HORIZONTAL SEPARATION OF SHOULDER AND PAVEMENT, FEBRUARY 1965

Shoulder Base Type	Shoulder Location	Research Section	Per Cent of Study Section at Indicated Opening Class 1	Class 2	Class 3	Class 4
CAM	Median	8	70	30	0	0
	"	9	43	34	13	10
	"	11	0	0	95	5
	"	25	67	33	0	0
	"	27	93	7	0	0
	"	33	41	0	53	6
	"	36	100	0	0	0
	Outside	7	27	51	18	4
	"	10	0	8	92	0
	"	24	95	5	0	0
	"	26	75	25	0	0
	"	28	100	0	0	0
	"	32	32	5	63	0
PAM	Median	1	20	41	39	0
	"	2	4	83	13	0
	"	3	0	4	74	22
	"	6	0	32	23	45
	"	13	5	63	26	6
	"	16	100	0	0	0
	"	17	0	100	0	0
	"	21	26	59	15	0
	"	23	27	42	31	0
	"	30	65	25	10	0
	"	35	18	82	0	0
	Outside	4	0	74	11	15
	"	5	0	50	30	20
	"	12	0	0	22	78
	"	14	0	72	0	28
	"	15	0	50	45	5
	"	20	42	11	39	8
	"	22	27	36	35	2
	"	29	9	13	46	32
	"	34	66	34	0	0
BAM	Outside	18	0	97	3	0
	"	19	0	100	0	0

Note:
Class 1 - Horizontal separation of less than 1/4 inch.
Class 2 - Horizontal separation of 1/4 inch to less than 1/2 inch.
Class 3 - Horizontal separation of 1/2 inch to less than 3/4 inch.
Class 4 - Horizontal separation of 3/4 inch or more.

Condition of Base Courses

Subsurface conditions, including the condition of the shoulder bases, were investigated initially in February 1965 through the use of a core drill.

Attempts at shoulder coring were made at the midpoint of each study section at distances of one, five, and nine feet from the pavement edge. A diamond coring bit of a diameter to furnish cores of four-inch nominal diameter was used in the operation.

As the coring operation progressed, it became evident that large portions of the CAM and PAM bases were not sufficiently cemented to furnish cores. More frequently than not, the base material disintegrated in the coring effort. Of 176 coring attempts in 35 research study sections, only 68 cores were recovered. In the drilling program, a cemented core three or more inches in length was considered to constitute recovery.

Core recovery data are tabulated in Table 9. It will be noted that poor rates of recovery were experienced in both the CAM and PAM base sections, with that in the CAM sections being the poorer. Perfect recovery was experienced in the BAM base section.

The poorest rate of core recovery was found to occur at the core location nearest the pavement edge. It has been speculated that the proximity of this location to the deicing salts in solution flowing downward at the pavement edge, or a lesser degree of compaction at this location as has been noted on some construction projects, or a combination of both, are responsible for the lower rate of recovery.

The coring in individual research study sections was not sufficient in amount to permit explorations of possible correlations between core recovery and area distress, transverse cracking, vertical displacement, and lateral separation. Core recovery was found not to be limited to the best sections with respect to amounts of area distress and the other defects measured; nor was the lack of recovery limited to sections showing poorly with respect to these defects.

To determine whether core recovery could be accepted as a realistic indication of whether or not the base materials were cemented as intended, attempts were made

TABLE 9

CORE DRILL SAMPLING OF SHOULDER BASE

			Sampling Distance From Pavement Edge								
			One Foot			Five Feet			Nine Feet		
Shoulder Base Type	Research Section	Shoulder Location	Total Coring Attempts	Cores Recovered	Per Cent Recovery	Total Coring Attempts	Cores Recovered	Per Cent Recovery	Total Coring Attempts	Cores Recovered	Per Cent Recovery
CAM	8	Median	1	0	0	4	1	25	1	0	0
	9	"	3	0	0	6	0	0	2	0	0
	11	"	0	-	-	1	0	0	0	-	-
	25	"	1	0	0	1	1	100	1	1	100
	27	"	1	0	0	1	1	100	1	0	0
	33	"	1	1	100	1	1	100	1	1	100
	36	"	1	1	100	1	1	100	1	1	100
	7	Outside	3	0	0	6	2	33	2	0	0
	10	"	1	0	0	1	0	0	1	0	0
	24	"	2	0	0	4	4	100	2	1	50
	26	"	3	1	33	2	1	50	1	0	0
	28	"	0	-	-	1	1	100	0	-	-
	32	"	1	0	0	1	1	100	1	0	0
PAM	1	Median	5	1	20	3	2	67	1	0	0
	2	"	2	0	0	6	3	50	3	1	33
	3	"	2	0	0	7	4	57	2	1	50
	6	"	5	0	0	4	3	75	0	-	-
	13	"	1	0	0	1	1	100	0	-	-
	16	"	0	-	-	1	0	0	0	-	-
	17	"	2	0	0	1	0	0	1	0	0
	21	"	1	1	100	1	0	0	1	1	100
	23	"	1	1	100	1	1	100	1	0	0
	30	"	2	2	100	2	2	100	1	0	0
	35	"	1	0	0	1	1	100	1	0	0
	4	Outside	2	0	0	3	3	100	1	0	0
	5	"	1	0	0	1	1	100	1	0	0
	12	"	1	0	0	1	0	0	1	0	0
	14	"	1	0	0	1	0	0	1	0	0
	15	"	1	0	0	1	0	0	1	0	0
	20	"	1	0	0	4	1	25	1	0	0
	22	"	1	0	0	4	1	25	1	0	0
	29	"	1	0	0	5	1	20	1	0	0
	34	"	1	0	0	1	1	100	1	1	100
BAM	18	Outside	3	3	100	5	5	100	2	2	100
	19	"	1	1	100	1	1	100	1	1	100

in May 1965 to cut two-foot square samples from the shoulder bases at locations adjacent to where coring attempts were made at midwidth of the shoulders. In this investigation, recovery was considered to have taken place when a cemented piece having a horizontal dimension at least the size of a four-inch diameter core and at least three inches in thickness was obtained. The results of this investigation were very similar to those of the coring operation, supporting the belief that the core recovery is a good indication of whether or not the base materials are in a reasonably good cemented condition at the time of coring.

The question of whether or not the planned cementation had once taken place where it was found not to be present, and had become lost for some reason prior to the coring operation, could not be answered in this study. A fairly high frequency of transverse cracking in some of the sections with a record of low core recovery would suggest that the base material was probably once in a cemented, semirigid state.

Cores three inches or more in length and pieces of similar size and larger recovered in the cutting operation were taken to the laboratory for testing compressive strength, durability, and moisture content.

Condition of Subbase

During the coring operation, and again during the operation that involved cutting of two-foot squares from the shoulders, the Grade 8 crushed stone subbase was inspected and samples taken at selected locations for physical testing and moisture content determination.

The subbase materials were found frequently to contain an excess of free water. Of 28 inspections of the subbase made during the square-cutting operation, it was found to be dry to moist at 5 locations, wet at 18 locations, and showing free water at 5 locations. During the course of these observations, it was noted that the topsoil and sod of the embankment slopes were often saturated with water at subbase elevation where full-width subbase was used and where the pavement grades were fairly flat.

Condition of Embankment Soil

Numerous samples of the embankment soil were taken through the core holes during the coring operation for physical tests and the determination of moisture content.

No free water was found in the embankment soil during sampling operations. Also, no indications of frost were found, although the sampling took place during freezing weather.

A few penetrometer bearing tests were made on the subgrade soils as an incidental part of the field investigation. One series of tests was made in February and March 1965, and another in May 1965. The first series was made during the process of the removal of soil samples through the core holes, and the second series during the cutting of the two-foot squares. In the second series, tests were made at subgrade level and one inch below following careful removal of the base and subbase materials.

Bearing values within the range of 0.7 to 4.5 tons per sq. ft. were determined for the subgrade soils. The lower values, most usually within the range of one to two tons per sq. ft., were found most frequently at subgrade level. No major differences were found between the February-March and the May readings. The bearing values that were determined cannot be interpreted to indicate anything unusual in the condition of support being offered by the soils involved. It was evident that substantial increases in bearing value take place within an inch or two below subgrade level.

Elevation Changes of Shoulder Components

In December 1965, settlement plates and reference rods were installed at two locations in each of Research Study Sections 10 and 12. The plates and rods were positioned so that elevation and thickness changes of the subgrade soil, the Grade 8 crushed stone subbase, and the stabilized shoulder base could be determined periodically at one foot from the outer edge, at midwidth, and at one foot from the inner edge of the shoulder at each of the four locations. While the information that has been obtained provides insight regarding the general magnitude of the seasonal movements taking place in the several layers of the shoulder system, it is limited by the fact that it presents no reference to the as-constructed condition.

The information presented in Figure 6 is typical of the data obtained from periodic elevation readings. For the purpose of evaluation, all readings have been referenced to the initial readings made on December 14, 1965. It will be seen that the shoulder structure and the embankment at subgrade level were subject to vertical upward movements during the winter months and to downward movements during the spring and summer months. From the limited data available, it appears that the subgrade soil has a major influence on the total volumetric change, with the shoulder structure components adding a lesser contribution.

Shoulder Trenching

To obtain a fuller view of the shoulder structures showing pronounced defects, two trenches were cut in March 1965 across the full width of the shoulders. The trenches were cut about 20 inches wide, down through the subbase, and outward at earth subgrade level to the embankment side slope. One trench was cut at Station 135+15 in Study Section 7, and the other at Station 159+05 in Study Section 9. Both trenches were cut in CAM base sections. Numerous samples of materials taken in the trench excavation were preserved for laboratory testing. Results of the laboratory tests are presented later in this report.

In both trenches the CAM material was found to be totally disintegrated and could be removed with a shovel. Both the cement-treated base materials and the crushed-stone subbase material were very wet and difficult to distinguish from one another by visual examination. Free water continued to flow from adjacent subbase material after removal of the subbase material in the trenched areas.

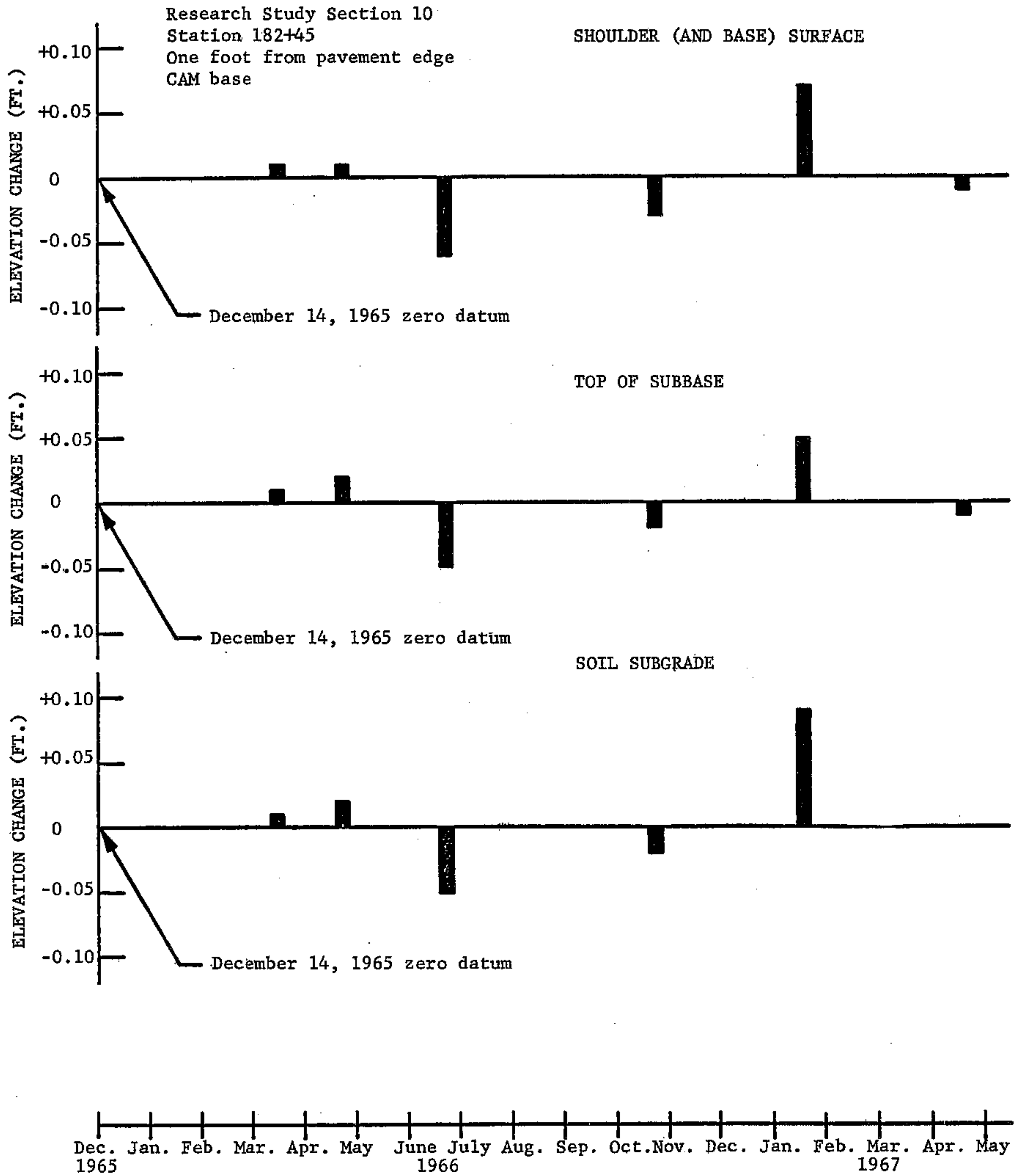


Figure 6. Typical changes in elevation of shoulder components.

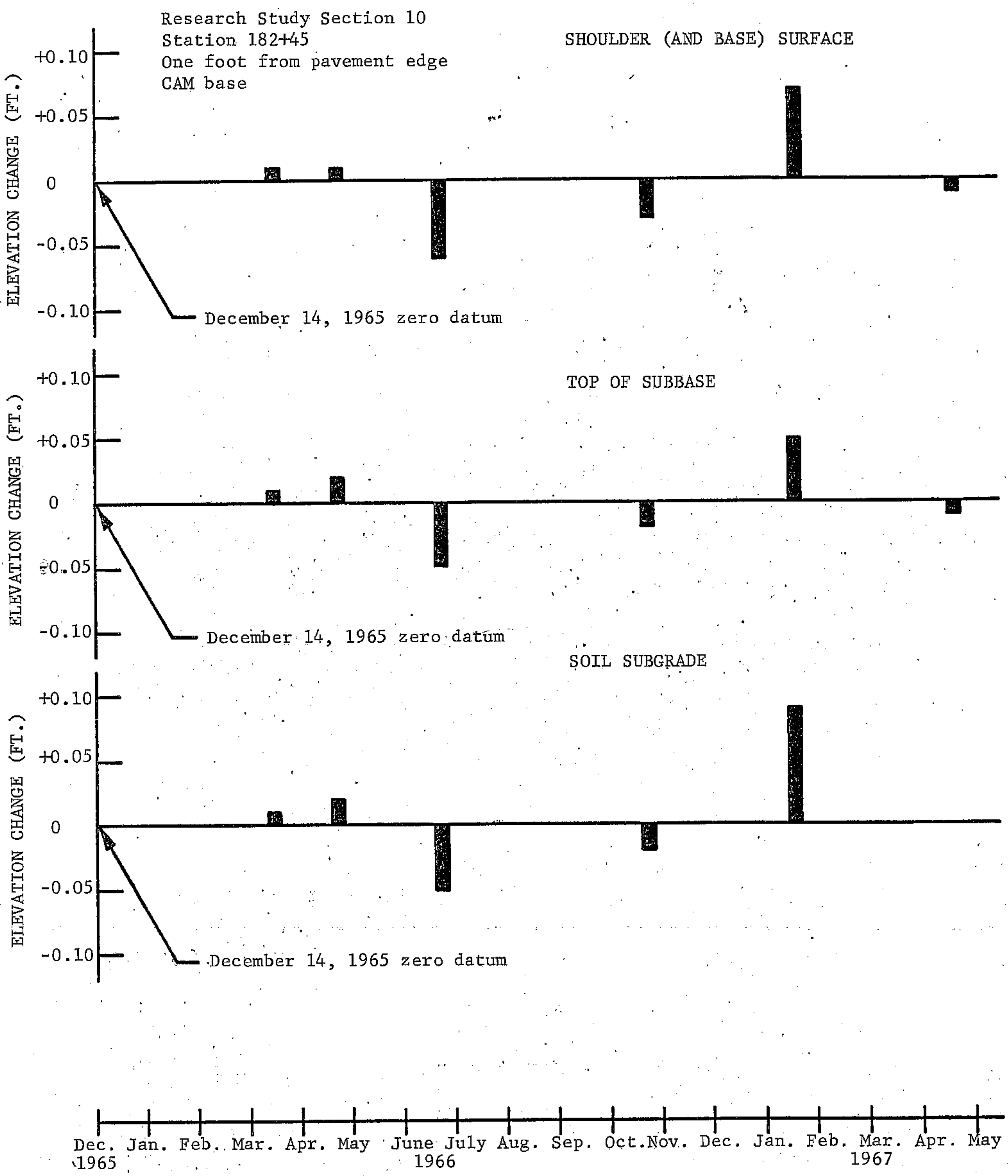
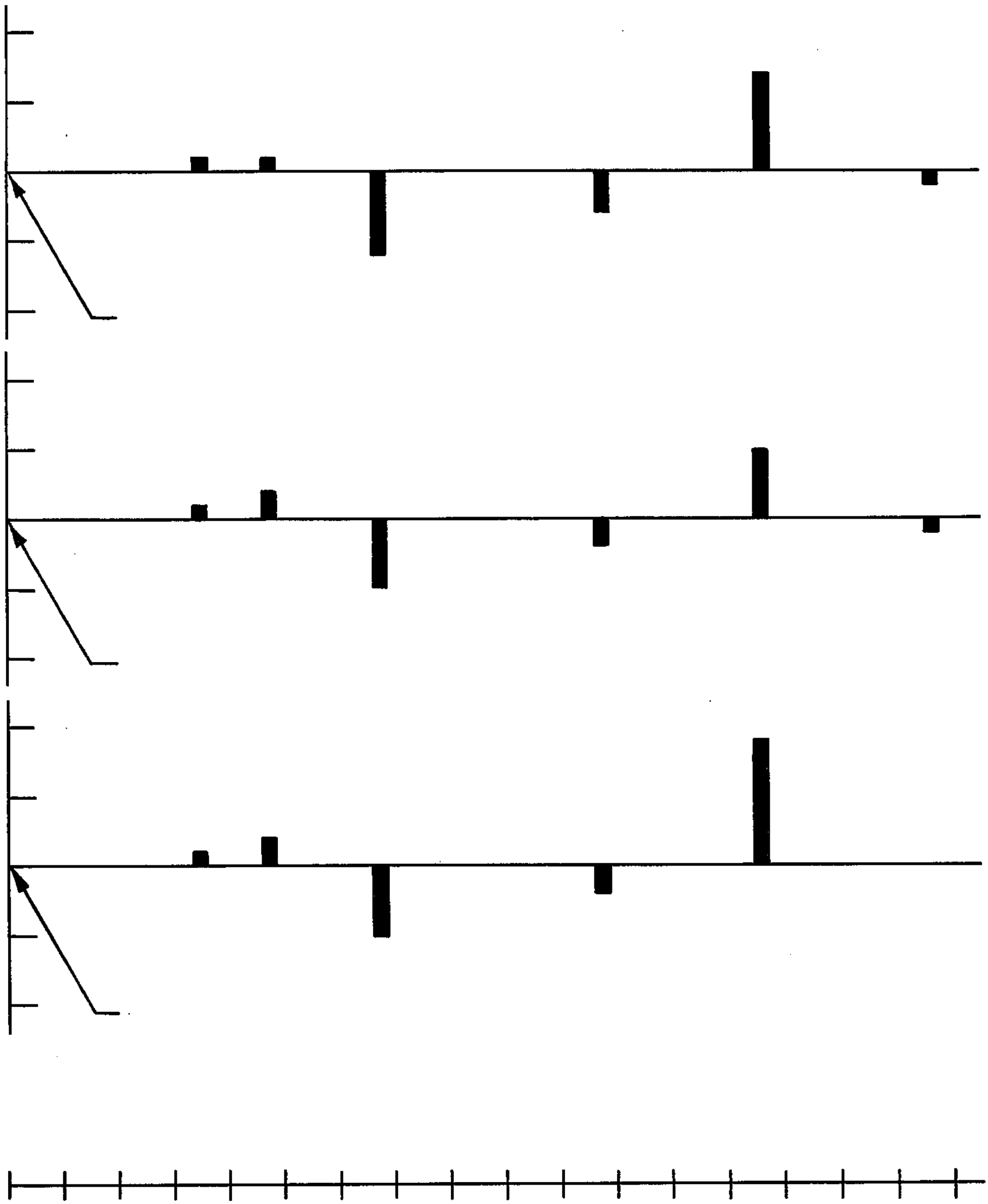


Figure 6. Typical changes in elevation of shoulder components.



After the trench examination was completed, the trenches were not immediately backfilled but instead covered with steel plates. In April 1965, immediately prior to backfilling, perforated pipe underdrains were installed at subgrade level and extending four inches under the pavement. Water was still noted to drain from the pipe several months after installation. Water drainage was also noted in other areas upon removal of the sod cover from the subbase material on the side slopes.

Frost Penetration

To gain some information on frost penetration in the study area, European-developed glass vial frost meters were installed at four locations. These frost meters consist of sealed water-filled glass vials which rupture when frozen to indicate depth of frost penetration.

Three of the frost meters were installed in Study Section 9, and another in Study Section 5. In Study Section 9, one meter was placed in the shoulder adjacent to the pavement edge, another in the side slope six inches from the shoulders, and the third in a bridge cone. The meter of Study Section 5 was placed in the center of the median. The frost meters were read once daily between February 12 and March 31, 1965. No frost penetration was noted after March 28.

Frost penetration results together with minimum and maximum air temperatures are charted in Figure 7. In general, the readings show a predictable pattern of frost penetration during colder weather. However, individual readings and day-to-day changes are sufficiently erratic to suggest some hesitancy in accepting the results without further testing of the frost meters.

Other Field Samples

With the knowledge that deicing salts and water-soluble sulphates can be harmful to portland cement concrete and similarly cemented materials, numerous samples of soil, subbase material, and free water present in the subbase were obtained for

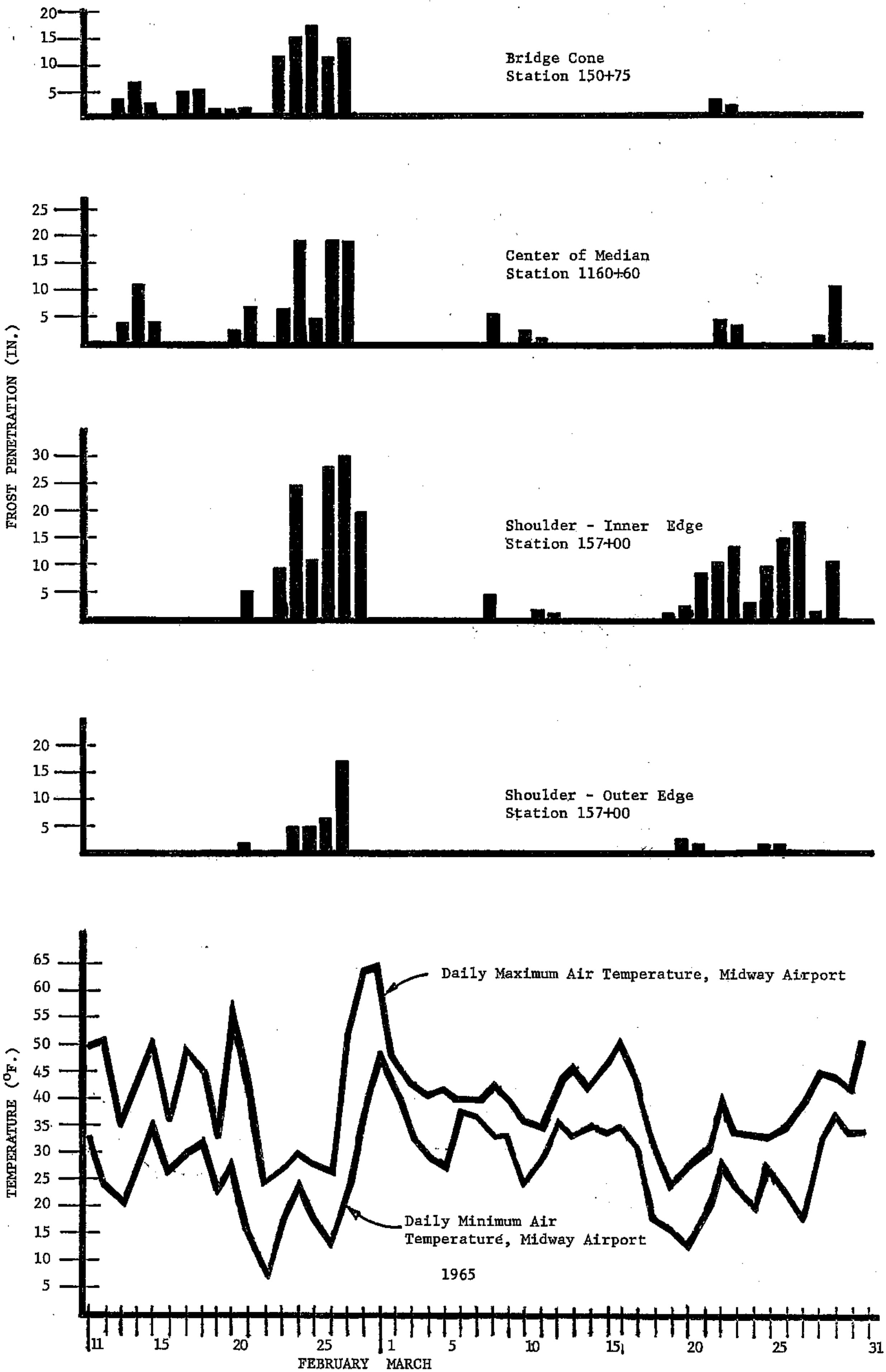


Figure 7. Measured frost penetration

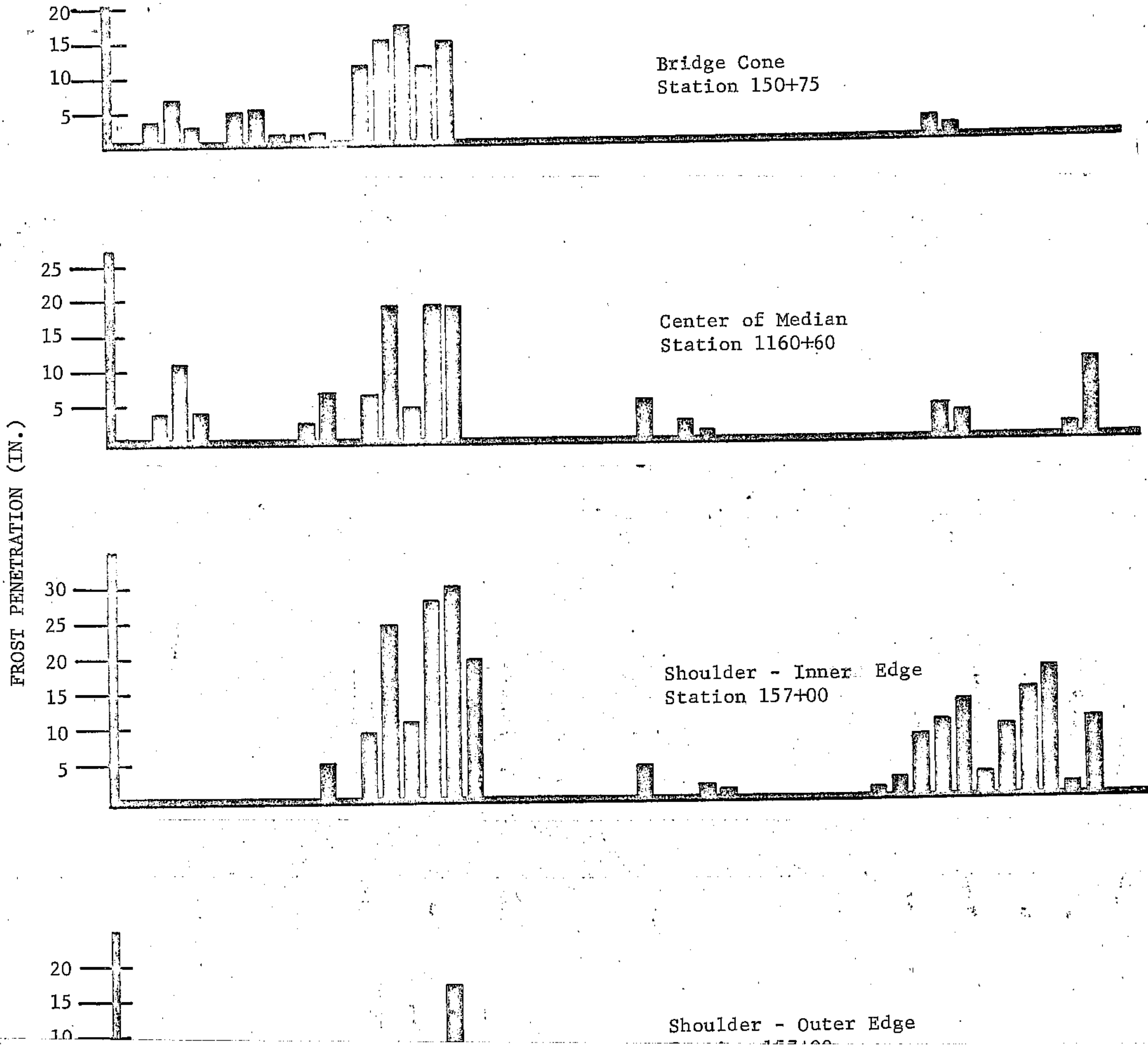
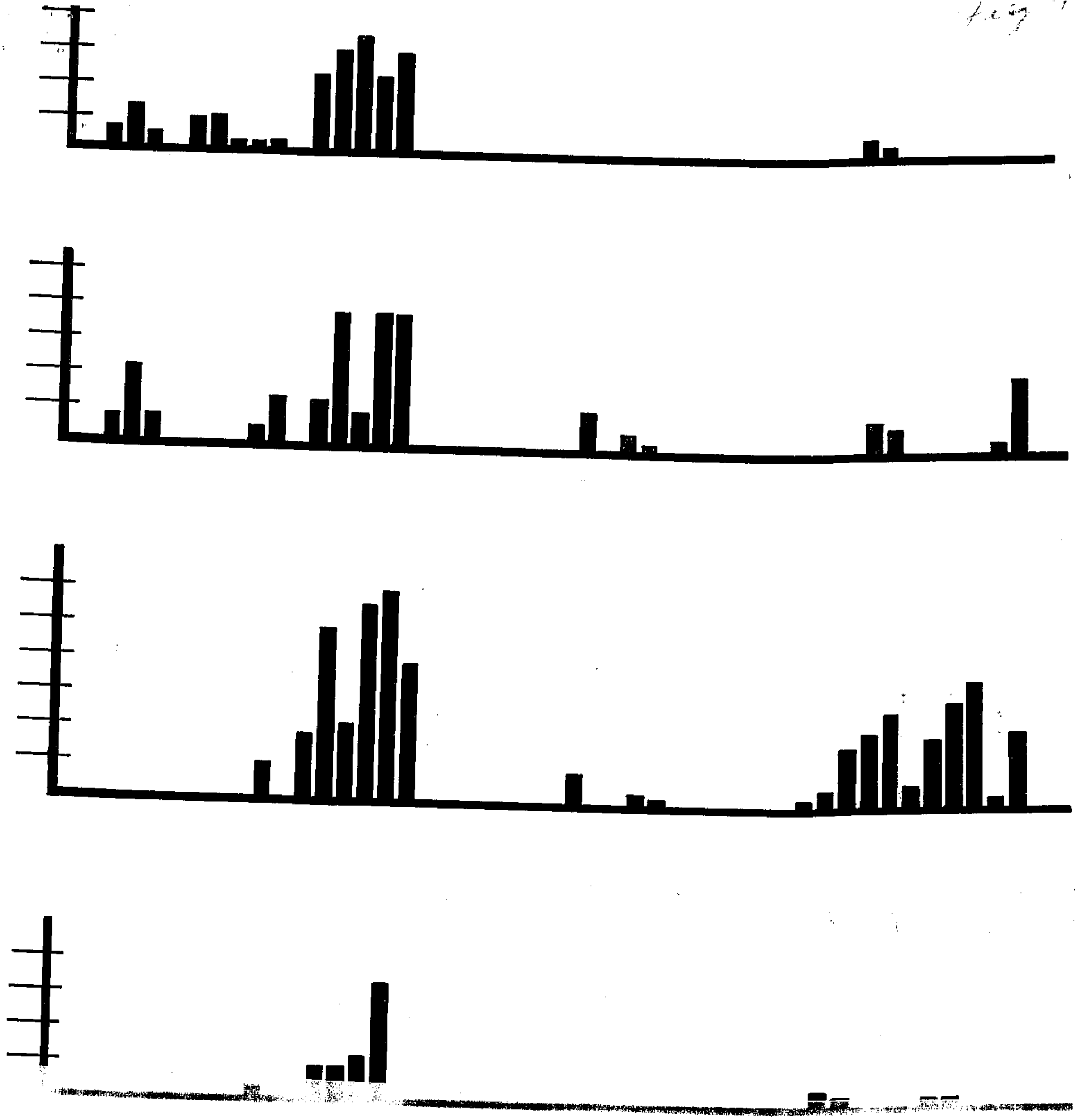

FROST PENETRATION (IN.)
20
15
10
5
Bridge Cone
Station 150+75
25
20
15
10
5
Center of Median
Station 1160+60
30
25
20
15
10
5
Shoulder - Inner Edge
Station 157+00
20
15
Shoulder - Outer Edge

fig 1



determinations of the concentrations of these chemicals. The results of the determinations are presented in the next section of the report.

LABORATORY INVESTIGATION

Base Course Materials

Compressive strength.--It will be recalled that the coring operation produced relatively few cores from the CAM and PAM bases for laboratory testing. From those that were recovered, representative cores were selected for laboratory testing of compressive strength. Results of the compressive strength tests are presented in Table 10. The values listed in Table 10 indicate that, where cementation was sufficient to permit core recovery, compressive strengths were of a relatively high order and that a considerable strength gain above the minimum seven-day compressive strength of 650 psi for CAM and 750 psi for PAM had occurred. The compressive strengths of CAM cores are generally somewhat higher than those of PAM cores. No relationship between shoulder position and compressive strength is detectable in the limited amount of data available.

Cores taken from the PAM bases often were observed to contain balls of flyash. Such mixtures could not be expected to perform as well as laboratory-prepared mixtures serving as the basis for design.

Durability.--Freeze-thaw durability tests were performed on several samples of CAM and PAM base course obtained during the two-foot square cutting investigation of May 1965. It will be remembered that the square-cutting operation produced results similar to the earlier coring operations so that relatively few samples were available for laboratory testing. Because of the irregular shape of the samples, three different specimen configurations were tested: (1) 4-inch diameter core cylinders; (2) 3 x 4 x 16-inch beams; and (3) 2-inch cubes. Duplicate specimens were made from each sample where possible.

All tests were conducted in general accord with the testing procedure of ASTM 560-67, Freezing-and-Thawing Tests of Compacted Soil-Cement Mixtures, but with various

TABLE 10

COMPRESSIVE STRENGTHS OF SHOULDER BASE CORES

Research Study Section	Distance of Core from Pavement Edge: 1 Foot	5 Feet	9 Feet
	(compressive strength, psi)		
	Cement-Aggregate Mixture (CAM)		
24		2060 2040	1660
25		3190	1520
27		490	
28		1400	
32		1610	
33	1660	1140	
36	2050 1910	1810	2020
	Pozzolan-Aggregate Mixture (PAM)		
1		1240	
2	1050	1220	1790
4		1360	
5		1310	850
13		1010	
21	1740		2050
22		1050	
23	1190	1170	
29		1180	
30	1290	1310	910
34		1220	1300
35		2220	

modifications. As one modification, one of each set of duplicate specimens was subjected to freezing and thawing in the presence of a five per cent sodium chloride solution instead of water as regularly used. The five per cent concentration was selected as representative of a severe condition of exposure that can be expected to occur in the field. Some of the samples were tested at or near the field moisture content; others were tested at the saturated surface dry condition. The results of the freeze-thaw tests are presented in Figure 8.

Soil-cement mixtures are usually considered to have adequate durability if the weight loss at 12 cycles of Standard ASTM Method of Test 560-57 does not exceed 14 per cent. The weight loss for pozzolan-aggregate mixtures at 12 cycles is not expected to exceed 10 per cent.

It will be noted in Figure 8 that the brine testing condition was far more severe than the standard water condition, and that specimens tested in brine failed in a very few cycles of testing. Several specimens will be seen to have performed quite well when tested in ordinary water.

The results of tests of additional samples in which brine was used as the testing medium have not been included in Figure 8 but showed similar results.

The significance of the results of laboratory tests such as have been performed in this study, in relation to field performance under conditions of exposure that exist on the Stevenson Expressway, is not known. More information is needed on this subject.

Subbase Material

Laboratory testing of samples of the Grade 8 crushed stone subbase material was limited to a few moisture content determinations. The results paralleled the visual observation of a frequent high degree of saturation in the field.

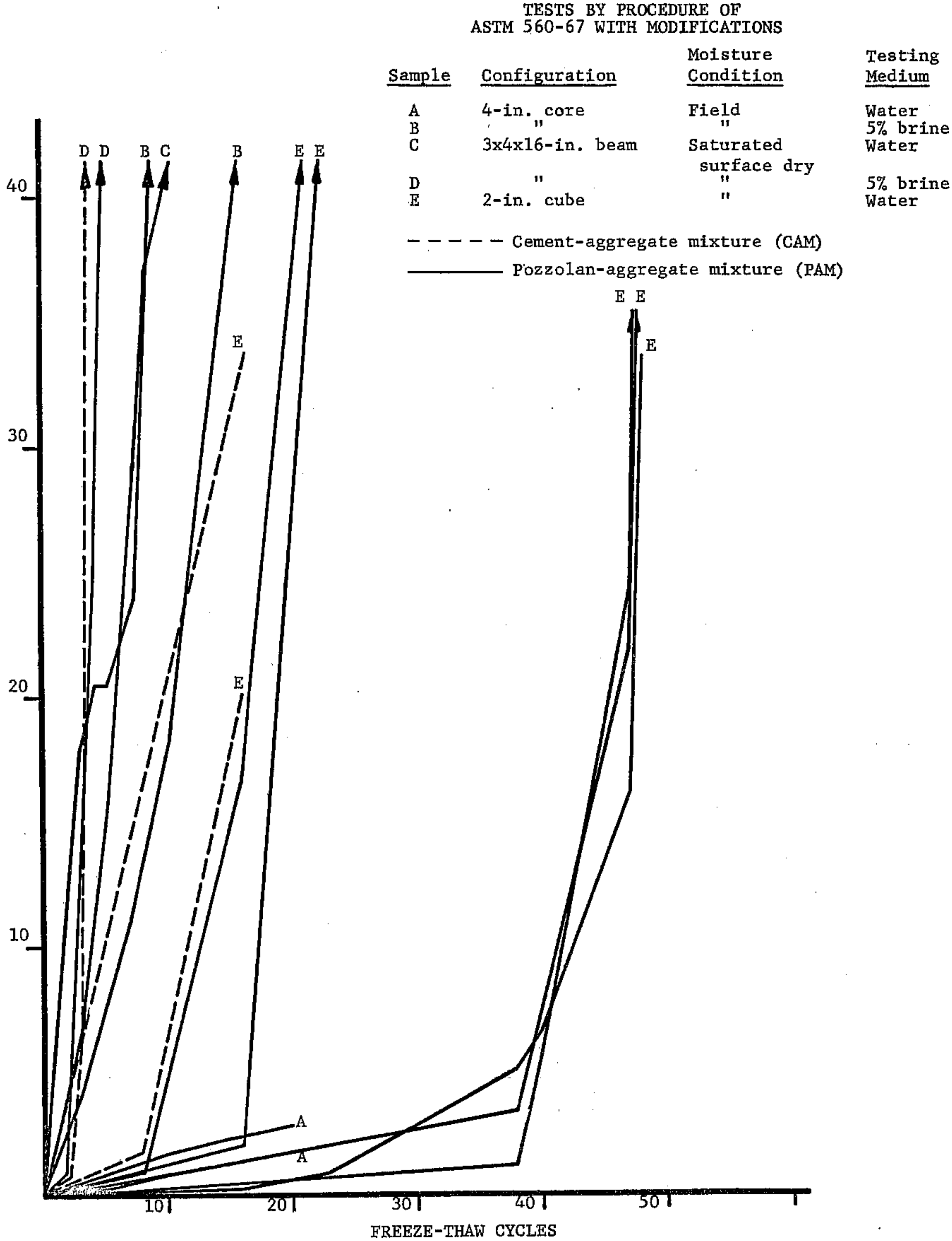


Figure 8. Results of freeze-thaw tests of field samples of cemented CAM and PAM.

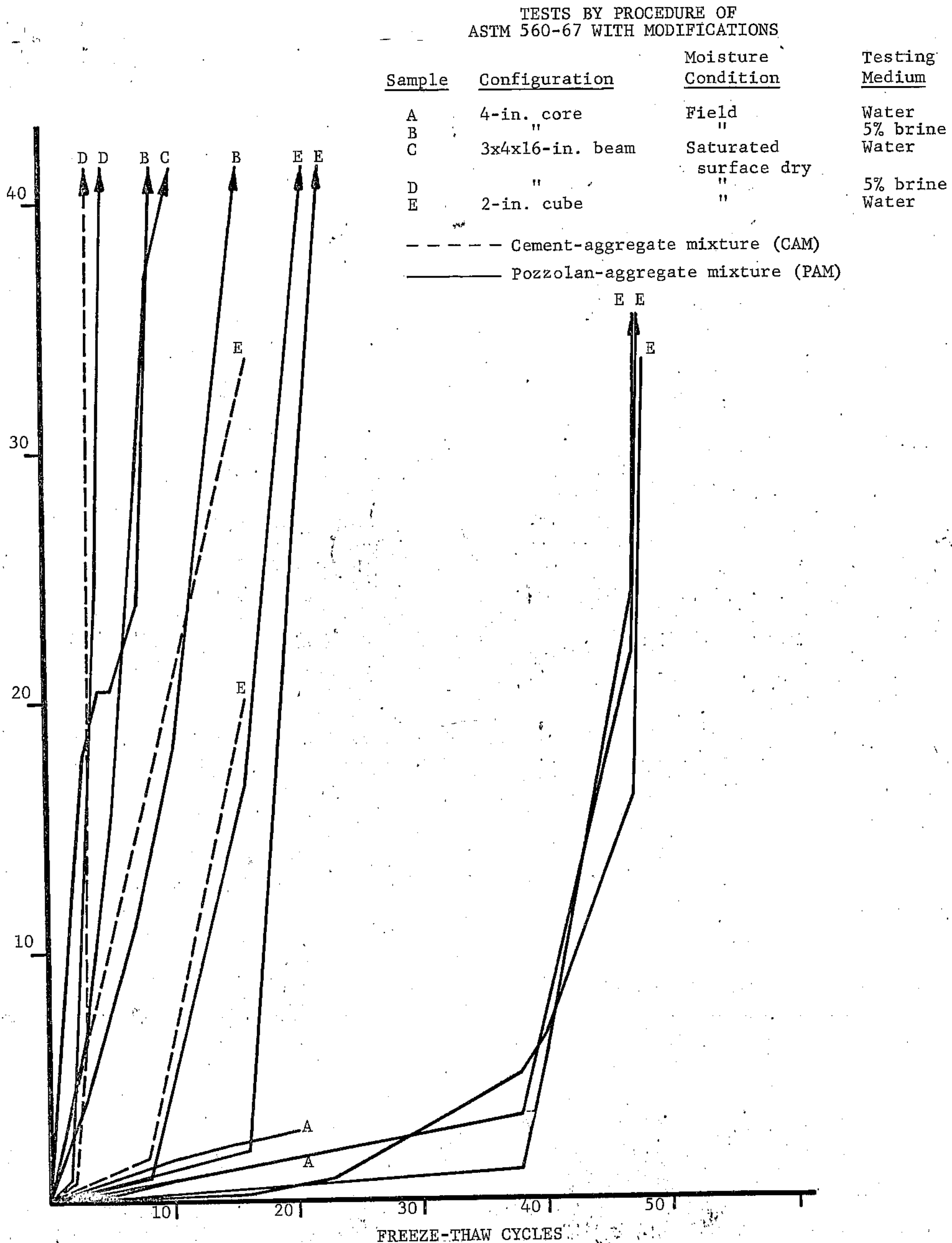


Figure 8. Results of freeze-thaw tests of field samples of cemented CAM and PAM.

7·7

Embankment Soils

Classification and moisture content.--The results of physical classification tests and of field moisture content determinations for samples of embankment soil taken from various locations in the area under investigation are shown in Table 11. The results indicate that the embankment soils are primarily of the A-6 and A-7-6 groups. These are the commonly available embankment materials over wide areas of Illinois and elsewhere, and are not unique to the area under consideration.

Field moisture contents will be seen to be mostly within a few percentage points of the plastic limits and most often slightly above the plastic limits. Past experience has indicated that fine-grained subgrade soils similar to those under consideration usually become fairly stabilized after construction at moisture contents slightly above the plastic limits.

CBR and swell.--Samples of subgrade soil taken from the two observation trenches and from two core holes were subjected to California Bearing Ratio (CBR) and swell tests. Results of this testing are shown in Table 12. The CBR values of 2.0 to 9.7 at 0.2-inch penetration are typical for the soils involved.

The recorded swell percentages of 0.5 to 1.9 per cent in four days of soaking following compaction at or near maximum density, and moisture gains of 0.5 to 2.7 per cent from an initial content at or near optimum, are indicative of soils not usually thought of as being highly expansive.

The foregoing test results indicate that the embankment materials, if at or near optimum moisture content at the time of construction of the shoulder structures, could not have contributed significantly to the vertical displacement of the shoulders. The test results do not rule out the possibility of considerable swell taking place if moisture contents were well below optimum at the time of shoulder placement. Because of the lack of knowledge of soil moisture conditions at the time of shoulder construction, the contribution that swell through moisture gain made toward the shoulder displacement must remain unresolved.

TABLE 11

PHYSICAL CHARACTERISTICS OF EMBANKMENT SOILS

Research Study Section	Station	Sample Depth (in.)	Field Moisture Content (%)	Atterberg Limits LL	PL	PI	Passing No. 200 (%)	Texture 4/ Sand (%)	Silt (%)	Clay (%)	AASHO Soil Classification
						Cement-Aggregate (CAM) Sections					
7	134+19	18-24 1/	15.9	21	14	7	66	35	44	21	A-4(6)
9	159+00	18-24 2/	-	47	22	25	86	--	--	--	A-7-6(15)
9	159+00	18-24 3/	-	45	18	27	89	--	--	--	A-7-6(15)
9	159+00	18-24	-	43	20	23	89	--	--	--	A-7-6(14)
9	157+04	30-36	21.6	41	16	25	89	11	28	61	A-7-6(14)
11	184+25	24-30	17.3	43	17	26	92	8	25	67	A-7-6(15)
32	7+00	-	15.1	30	14	16	70	30	28	42	A-6(9)
36	20+00	-	12.6	33	15	18	68	32	28	40	A-6(10)
						Pozzolan-Aggregate (PAM) Sections					
3	1116+10	6-12	20.7	37	17	20	78	22	34	44	A-6(12)
3	1116+10	36-42	17.6	41	17	24	88	12	34	54	A-6(14)
5	1165+00	6-12	21.7	32	15	17	80	20	42	38	A-6(11)
6	1174+46	12-18	17.9	42	17	25	86	14	27	59	A-7-6(14)
14	195+15	12-18	17.7	42	16	26	93	7	28	65	A-7-6(15)
15	254+00	24-42	-	46	18	28	90	10	27	63	A-7-6(16)
20	534+50	-	16.4	29	14	15	80	20	35	45	A-6(10)
21	552+50	-	14.6	33	16	17	83	17	35	48	A-6(11)
23	578+50	-	16.9	30	16	14	78	22	35	43	A-6(10)
34	215+00	-	20.2	41	17	24	85	15	33	52	A-7-6(14)

1/ Sample 1 foot from pavement edge
2/ Sample 5 feet from pavement edge
3/ Sample 9 feet from pavement edge
4/ Sand 2.0-.05 mm.
Silt .05-.005 mm.
Clay less than .005 mm.

TABLE 12

CALIFORNIA BEARING RATIO AND SWELL

Research Study Section	Distance from Pavement (ft.)	Depth of Sample (in.)	CBR (0.2" pene.)	Swell Test 2/ Swell (%)	Swell Test 2/ Moisture Gain (%)
6				4.4 1/	
7			8.0	0.6	1.0
7			9.7	0.5	1.1
9	1	16-24	3.5	1.8	2.7
9	1	16-24	5.9	1.4	2.3
9	5	16-24	4.1	1.6	1.9
9	5	16-24	4.7	1.9	2.2
9	9	16-24	2.0	1.1	0.5
9	9	16-24	3.2	1.3	0.6
10				3.0 1/	

1/ Soaked in water for 7 days; others soaked 4 days

2/ Moisture gain when compacted at or near optimum

Embankment soil permeability.--Fine-grained soils in AASHO classification A-6 and A-7-6 are considered to be highly impermeable, particularly when reworked from their natural state as in embankment construction. This was verified by permeability tests of three samples which showed coefficients of permeability of 0.2, 0.3 and 1.0 feet per year. Such soils are practically impervious, do not contain free water except perhaps when ice lenses melt, and do not respond well to underdrains.

Frost susceptibility.--Fine-grained soils of the A-6 and A-7-6 classifications, the primary embankment materials in the area in question, are known to be frost susceptible and to heave if exposed to freezing in the presence of free water. The most likely free water to cause heave along the expressway was that which entered from the surface. The imperviousness of the A-6 and A-7-6 soils, the use of deep side ditches in cuts, and the construction of a major portion of the roadway in embankment section excludes the possibility of ground water as a major factor contributing to heave.

Deleterious Chemicals

Sodium chloride and calcium chloride, and water soluble sulphates, are known to have adverse effects on the durability of mixtures containing portland cement or lime. Samples of free water and materials of the expressway were taken to investigate the concentration of these chemicals to assess their responsibility with respect to the uncemented condition of the CAM and PAM bases.

Sodium chloride.--Because of the use of a considerable quantity of sodium chloride in deicing operations on the expressway, a limited sampling and testing program was initiated to provide some insight on the concentrations likely to be present in runoff water and in the disintegrated base materials. It is known that concentrations in water in the range of perhaps 2 to 5 per cent are particularly detrimental to concrete, and presumably to other mixtures containing portland cement or lime.

Samples of free water present in the subbase were collected during the field investigation in March. The sodium chloride contents, as will be noted from Table 13, are in the range known to have harmful effects on concrete.

Samples of the disintegrated PAM base were also taken and tested for sodium chloride content to gain some information on the concentrations to be found in this material. The results of the testing are shown in Table 14. The information that was obtained is not sufficient to relate salt concentration to behavior; however, the presence of considerable quantities of salt in the base is shown.

pH values.--Extremely high or low pH values (the high showing strong alkalinity and the low strong acidity) are known to be indicative of the presence of chemicals harmful to concrete (and presumably similar products), and to plant growth. A series of pH tests made on roadway sod and soil samples taken in May and June 1965 showed a range from slightly acid to slightly alkaline, with a majority showing slight alkalinity. Neither the acidity nor alkalinity exhibited at this point in time can be considered especially harmful to plant growth, nor to adjacent concrete or the CAM and PAM bases.

Sulphates in soil.--Concentrations of water-soluble sulphates in soils and water in excess of 0.20 per cent can be harmful to products containing hydrated lime and portland cement with which they may be in contact. To check the possibility that sulphates from the soil used in embankment construction might be contributing to the disintegrated condition of the CAM and PAM bases, several samples of free water and of soil taken during the trench investigation were tested for sulphate content. Results of the tests are shown in Table 15. It will be noted in the table that sulphate contents are well below the concentration which could be detrimental to products containing lime or portland cement.

CLIMATOLOGICAL DATA

Because of the probability that the shoulder displacement of the Stevenson Expressway is related to frost activity and the presence of moisture, temperature

TABLE 13

SODIUM CHLORIDE CONTENT OF FREE WATER FROM BASE COURSE

Research Study Section	Station	Location	Sodium Chloride Content (%)
7	137+15	5 ft. from pavement edge	3.4
7	137+15	9 ft. from pavement edge	1.7
9	159+00	1 ft. from pavement edge	2.5
9	159+00	5 ft. from pavement edge	2.2
9	159+00	9 ft. from pavement edge	2.8
21	554+00	1 ft. from pavement edge	4.1
21	554+00	5 ft. from pavement edge	4.1
21	554+00	9 ft. from pavement edge	4.3

TABLE 14

SODIUM CHLORIDE CONTENT OF PAM BASE COURSE

Station	Pavement	Shoulder	Sodium Chloride Content At Pav't. Edge (%)	Centerline (%)	Outside Edge (%)
193+75	Eastbound	Median	0.068 0.129	0.261 -	0.138 0.038
1173+50	Westbound	Median	0.017 0.110	0.042 0.195	0.075 0.067
217+00	Westbound	Median	0.015 0.066	0.075 0.015	0.146 0.130
141+00	Eastbound	Median	0.017 0.074	0.003 0.019	0.147 0.014

*The upper figures represent the per cent of salt in samples from the upper half of the base course (approximately 2 inches below top surface); lower figures are per cent of salt in samples from the lower half of the base course (approximately 2 inches above bottom of base).

TABLE 15

WATER-SOLUBLE SULPHATE CONCENTRATION

Research Study Section	Station	Location	SO_4 Content (%)
		Subgrade Soils	
7	137+10	Beneath shoulder	0.04
7	137+10	Outside shoulder	0.02
9	158+95	Beneath shoulder	0.01
9	158+95	Outside shoulder	0.01
		Free Water	
7	137+15	5 ft. from pavement edge	0.03
		9 ft. from pavement edge	0.02
9	159+00	1 ft. from pavement edge	0.06
	159+00	5 ft. from pavement edge	0.06
	159+00	9 ft. from pavement edge	0.03
21	554+00	1 ft. from pavement edge	0.09
	554+00	5 ft. from pavement edge	0.10
	554+00	9 ft. from pavement edge	0.08

and precipitation data for the area are of interest. A summary of such data based on records of nearby Midway Airport weather station are presented in Table 16. It will be noted that average monthly temperatures for the period in question were mostly somewhat below normal; that average minimum temperatures during the winter period were well below freezing; that precipitation during the final phase of construction when the shoulders were placed was well below normal; and that late winter and early spring precipitation was above normal.

While the information at hand is not sufficient to develop any numerical relationships between vertical displacement of the shoulders and temperature and precipitation, it seems appropriate to speculate that dryer-than-normal conditions during shoulder placement, followed by wetter-than-normal and colder-than-normal weather, may well have contributed to the unusual severity of the shoulder displacement that took place on the Stevenson Expressway.

USE OF DEICING SALTS

With the knowledge that the sodium chloride and calcium chloride used as deicing agents can be harmful to portland cement concrete and other products containing cement and lime, records of salt application on the Stevenson Expressway during the winter of 1964-65 were reviewed. It was found that 9669 tons of deicing agent were used in 28 separate applications. Sodium chloride was the deicing agent except for eight tons of calcium chloride. This usage, which amounted to about 18 pounds per square yard of pavement, suggests a high rate of exposure of both pavement and shoulder base courses to the harmful influence of deicing agents.

DISCUSSION

The vertical movement that caused the bituminous-paved shoulders of the Stevenson Expressway to become generally higher than the adjacent portland cement concrete pavement is believed to be primarily an upward displacement of the shoulders

TABLE 16

TEMPERATURE AND PRECIPITATION DATA

Month	Temperature: Average Daily Maximum (°F)	Average Daily Minimum (°F)	Mean (°F)	Departure From Normal (°F)	Precipitation: Total (in.)	Departure From Normal (in.)
1964						
August	82.2	61.2	71.7	-2.5	2.19	-0.97
September	75.9	55.8	65.9	-0.2	2.50	-0.23
October	63.1	39.1	51.1	-4.0	0.20	-2.58
November	53.3	34.1	43.7	+3.8	1.26	-0.94
December	33.8	20.9	27.4	-1.7	1.87	-0.03
1965						
January	32.4	16.6	24.5	-1.5	4.09	+2.23
February	36.0	18.7	27.4	-0.3	1.76	+0.16
March	35.6	24.7	30.2	-6.1	3.44	+0.70
April	56.0	39.3	47.7	-1.3	4.21	+1.17
May	74.6	53.3	64.0	+4.0	1.47	-2.26

Note: Temperature and precipitation data are based on Midway Airport weather station records.

rather than settlement of the pavement. Previous experiences with widening strips and new pavements abutting older pavements that could be expected to have attained a measure of vertical stability, support this belief. Construction records which would allow a positive determination of the location and direction of such vertical movements are not normally available and are not available for the Stevenson Expressway. Conclusions that have been drawn as a result of the present study and recommendations that are offered have been made on the premise that the prime vertical movement has been an upward displacement of the shoulders.

The lateral displacement that caused shoulder and pavement to become separated must be accepted to be an outward movement of the shoulder except for the minor inward movement of the pavement (probably less than 1/8 inch) resulting from contraction in cold weather.

The vertical and lateral shoulder displacements occurred with all types of shoulder base courses (cement-aggregate, pozzolan-aggregate, and bituminous-aggregate), but were of consequence only where the cement-aggregate and pozzolan-aggregate base courses had been used.

Longitudinal cracks often present about a foot from the pavement edge, and the concentrated random cracking (area distress) that was seen frequently to lie between the longitudinal cracks and the pavement edge, were limited to the cement-aggregate and pozzolan-aggregate base sections. Only minor differences in extent and severity of defects were noted between cement-aggregate and pozzolan-aggregate base sections.

Within the limitations of the study, no positive relationships could be detected between the amounts of vertical and lateral displacement of the shoulders, the formation of longitudinal cracks, the random concentrated cracking and the transverse cracking.

Three possible locations of heave of the shoulders are present: (1) the embankment soil; (2) the subbase material; and (3) the disintegrated base material.

The embankment soil is known to be capable of heaving through frost action in the proper moisture and temperature environment, and to be capable of swelling in the proper moisture environment. Past knowledge of the behavior of similar soil, and the results of permeability tests conducted as part of the present study, indicate that a strong source of free water close to the location of the frost action is necessary for substantial heave to take place. Ample evidence of surface water that had penetrated the subbase material and otherwise come in close proximity with the embankment soil suggests the existence of a water condition conducive to frost heave in the embankment soil. The presence of this free water also suggests an opportunity for swell through moisture gain. With the magnitude of swell of the embankment material largely dependent upon its moisture content and density at the time of shoulder placement, about which insufficient knowledge exists, no assessment can be made of its contribution to the total heave. Laboratory tests indicate that swell from an initial condition of standard optimum moisture and maximum density would not be great.

The subbase material is known also to have sufficient fines to be susceptible to heave through frost action. Here again, ample evidence of the presence of sufficient water to promote such action was found. Swell through moisture gain in the subbase aggregate is not considered to be a major contributor toward the shoulder displacement.

Disintegration of cemented base materials is believed to have been a certain contributor toward the heave. Laboratory tests that were not an immediate part of the present study, but which were conducted on samples of cement-aggregate and pozzolan-aggregate mixtures fabricated to represent the cemented mixtures of the Stevenson Expressway, lend substantiation to this belief.

Without knowledge of the initial positions of the shoulder structure components and of the underlying soil subgrade, it is not possible to show positively the sources of the volumetric changes that have taken place and the relative contributions of each. Recent studies in which plates were placed at the interfaces of the shoulder components of the Stevenson Expressway and the elevations read periodically have shown that the underlying subgrade soil appears to have a major influence on the total volumetric change, with the shoulder structure components adding a lesser contribution.

Water that ran off the pavement and reached underlying materials through the opening between pavement and shoulder, and through cracks that formed in the pavement surface, is undoubtedly the principal water causing the displacement that has taken place. The openness of the subbase aggregate combined with the sod cover that led to the entrapment of the water for long periods of time undoubtedly aggravated the condition.

Laboratory tests have shown the cement-aggregate and pozzolan-aggregate mixtures of the Stevenson Expressway shoulder bases to be particularly subject to deterioration under freezing and thawing in the presence of brine. The brine derived from the use of deicing salts was undoubtedly a major contributor to the disintegration of the cement-aggregate and pozzolan-aggregate bases. The degree to which the deterioration would have taken place had the water not contained deicing salts is not known.

Experience has shown that cement-aggregate and pozzolan-aggregate mixtures show better strength gain and resistance to disintegration from freeze-thaw activity when seasoned under conditions that involve some drying rather than under totally saturated conditions. Whether or not the disintegration would have occurred if more seasoning time under a lesser degree of saturation had been available before the bases were subjected to freezing temperatures in the presence of large amounts of free water and brine is not known.

It has been mentioned that all three shoulder base mixtures were found to be associated with vertical and horizontal displacement of the shoulders; also, that the most severe displacements were associated only with the cement-aggregate and pozzolan-aggregate mixtures. It is possible, but not certain, that the occurrence of the displacements set in motion the forces that led to the disintegration and to the cracking and area distress associated only with the cement-aggregate and pozzolan-aggregate base mixtures. Regardless of the triggering force, the several deficiencies most probably progressed simultaneously, one aggravating the other. The better resistance of the bituminous-aggregate base mixture to freeze-thaw deterioration, and perhaps the ductility of the asphalt itself, are probably most responsible for the better behavior of the bituminous-aggregate base shoulders.

CONCLUSIONS

The displacement and attendant distress suffered by the paved shoulders of the Stevenson Expressway appear to have originated through the exposure of frost-susceptible and expansive material to excessive amounts of surface water. Several factors seem to have acted either in combination or separately to aggravate the condition, among them being:

(1) an embankment soil especially susceptible to frost expansion when exposed to large quantities of water; also one capable of expansion when exposed to moisture.

(2) a subbase material somewhat capable of frost expansion when exposed to water, but also capable of serving as a source of free water to be drawn upon by contiguous materials that are less frost resistant.

(3) base materials lacking adequate durability when exposed to freeze-thaw cycles in the presence of water or brine.

RECOMMENDATIONS

The investigation has indicated the following:

New Construction

(1) Mixtures substantially more resistant to freezing-and-thawing deterioration in the presence of water and brine than the cement-aggregate and pozzolan-aggregate mixtures of the Stevenson Expressway should be selected for use in shoulder bases.

(2) Structural designs should be revised to provide for a substantially more positive means for removal of surface water and brine entering the structure; or to provide a substantially more positive means of sealing against the entrance of surface water; or both.

Existing Construction

(1) Steps should be taken to improve drainage of existing aggregate subbases.

(2) The longitudinal separation between pavement and shoulder, shoulder cracks, and pavement joints should be sealed against the entrance of surface water and brine by the most positive means at hand.

Experimentation

The value of the present investigation has been limited by a lack of adequate knowledge of many details regarding conditions prevailing prior to the occurrence of the shoulder displacement and deterioration. Before remedial measures can be applied with the desired degree of confidence, more information is needed on the relative effects that each of the factors of influence has in the development of such conditions as occurred on the Stevenson Expressway. For example, more needs to be known about the expansive characteristics of embankment soils compacted to the required density but subjected to a drying environment prior to covering. Experimentation that begins at the design stage and follows through the construction and service stages should be conducted to provide this information. This experimentation should be applied to the materials of construction as well as to structural design.

PHOTOGRAPHS TAKEN DURING FIELD INVESTIGATION

February - May, 1965

Photo 1. Severe area distress with water accumulation at shoulder-pavement interface.

Photo 2. Close-up of severe area distress.

Photo 3. Typical area distress along median shoulders.

Photo 4. Unusual area distress along outside edge of shoulder.

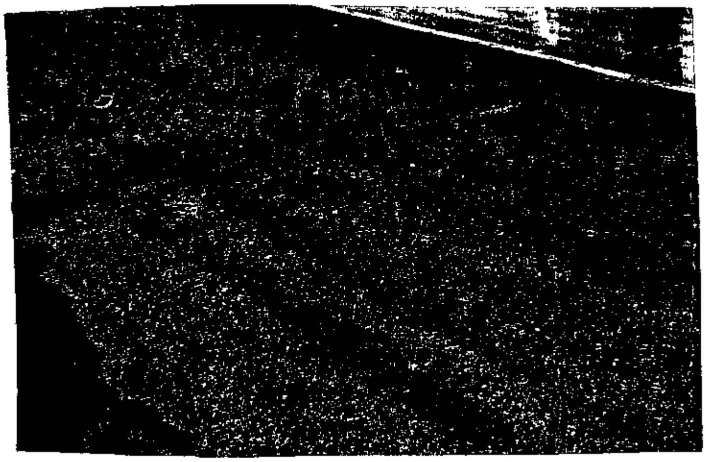


Photo 5. Typical transverse crack in bituminous concrete over CAM base.

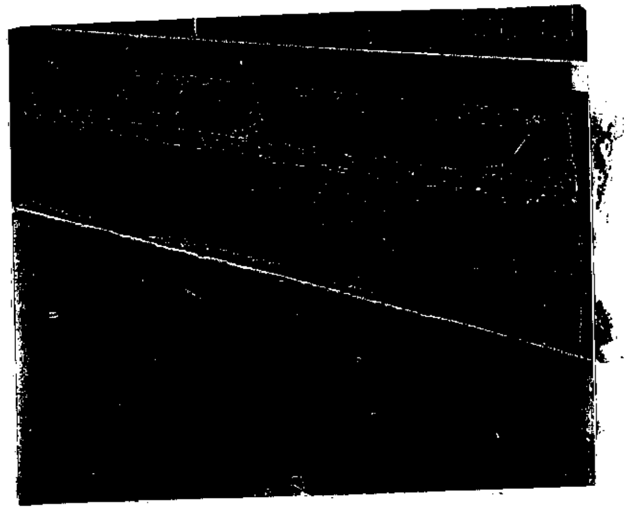


Photo 6. Typical upward vertical displacement of shoulder.

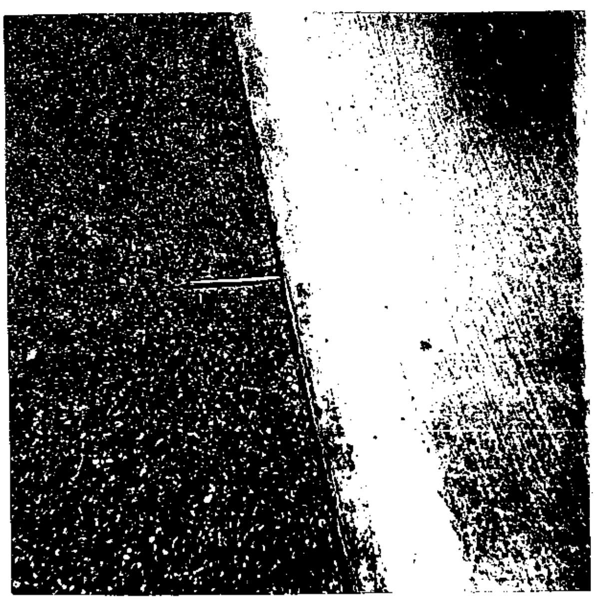


Photo 7. Typical separation of shoulder and pavement.

Photo 8. Unsuccessful coring attempt in disintegrated base material.

Photo 9. Successful coring attempt.

Photo 10. Two-foot square sample showing disintegrated base material.

Photo 11. Excavated shoulder trench showing water accumulation on subgrade soil.

Photo 12. Glass vial frost meter installed in shoulder adjacent to pavement.

Photo 13. Water draining from subbase after sod and topsoil removal.